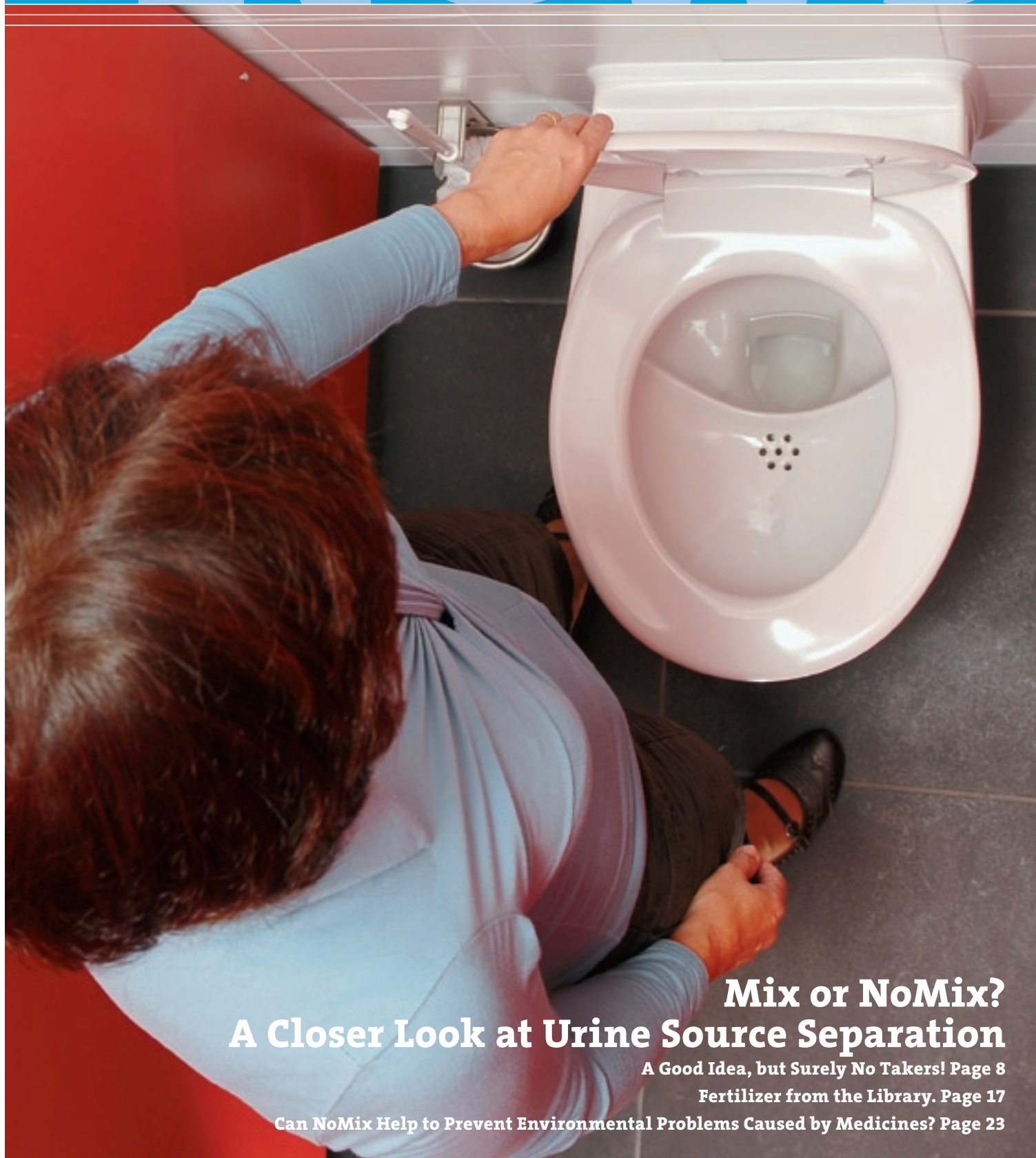


Eawag

News



Mix or NoMix? A Closer Look at Urine Source Separation

A Good Idea, but Surely No Takers! Page 8

Fertilizer from the Library. Page 17

Can NoMix Help to Prevent Environmental Problems Caused by Medicines? Page 23



Willi Gujer, member of the Eawag Directorate, Professor of Urban Water Management at the ETH Zurich

NoMix, an Option to be Taken Seriously

My first presentation on the curious idea of separately draining and treating urine was delivered in a small, out-of-the-way lecture room. That was in 1996, at a large conference held by the International Association of Water Quality (IAWQ, now the IWA). Only a few delegates had found their way to this room, and a number of colleagues even felt obliged to attend my talk. Today, presentations on the NoMix technology are given to capacity audiences at the main sessions of the same conference, and the number of publications is growing exponentially.

In our pursuit of cost-effective water pollution control solutions, building on notions of sustainability, we were initially concerned with the idea of recycling the nutrients in urine, especially phosphorus. In the meantime, other aspects have come to the fore; for the media, the fate and significance of micropollutants in urine – i. e. hormones and residues of medicines – have greater appeal than nutrients for which reliable elimination technologies have, of course, been available for years.

As well as the technical and scientific questions, the NoMix technology projects raised new and fascinating aspects for me as an engineer: the involvement of households and the direct contact with users were unusual. We also had to learn how to interact with the sanitary industry, and in these dealings we remain only partly successful. Political decisions suddenly play a quite different and more important role than in the development of a conventional wastewater treatment plant project. In all these new tasks, we are increasingly dependent on collaboration with economists and social scientists – a trend that is not unique to this project.

The Novaquatis team courageously devoted itself, across a broad front, to a project that was initially judged to be interesting in its scope but overall tended to be dismissed as somewhat exotic. This has now become a leading project internationally, attracting interest and providing answers worldwide. The fact

that such large-scale, long-term (cross-cutting) projects are even possible is one of the strengths of Eawag. If Eawag were purely a university institute, greater weight would have to be attached to short-term success.

Together with all those who participated in Novaquatis, I am pleased to see the project brought to a successful and fruitful conclusion. I hope that practitioners will now also be courageous enough to implement our findings. If at first the beneficiaries of this process are not, as originally intended, industrialized countries, but primarily fast-industrializing nations, our initial hopes will be more than fulfilled.

Cover photo: The NoMix toilet (Roediger model) installed in Eawag's Forum Chriesbach building and at the Basel-Landschaft Cantonal Library in Liestal. The urine outlet is only open when a user is seated on the toilet. When the user stands up to flush, the outlet is closed, so that urine is drained into the tank undiluted. © Ruedi Keller, Zurich

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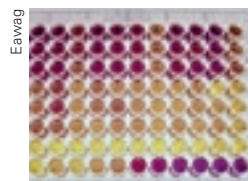


Producing a fertilizer from urine is an innovative enterprise. The process is being carried out for the first time in Switzerland at the Cantonal Library in Liestal, which is fitted exclusively with NoMix toilets.

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When urine is processed, it is necessary to ensure that residues of medicines and hormones are not released into the environment. In the Novaquatis project, a specific test method was developed.

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Spotlight on NoMix



Tove A. Larsen, chemical engineer, and Judit Lienert, biologist, co-leaders of the cross cutting Novaquatis project at Eawag

Novaquatis, an inter- and transdisciplinary Eawag project, investigated urine source separation and treatment as an option for modern wastewater management. The results indicate that the so-called NoMix technology is a highly versatile innovation, offering advantages in a variety of scenarios. In particular, it could help to resolve global nutrient-related issues.

Is it possible to make wastewater management more sustainable by collecting urine at source and treating it separately? Interest in this question at Eawag dates back to the mid-1990s [1]. The underlying consideration is that while urine accounts for less than 1% of all wastewater, it contributes the bulk of nutrients. If urine was diverted and treated separately from other wastewater streams, nutrients could be more effectively eliminated than is usually the case in Switzerland today. This would permit the construction of smaller wastewater treatment plants, designed to optimize the degradation and retention of dissolved and particulate organic matter in wastewater. In addition, nutrients could be recycled to agriculture. This is particularly important with regard to phosphorus, since readily available and high-quality reserves will be exhausted in the medium term. In order to study the feasibility of the NoMix technology, Eawag initiated the cross-cutting Novaquatis project. This inter- and transdisciplinary programme ran from 2000 to 2006.

The project activities were divided into nine work packages (Fig. 1). For the most part, the results of the Novaquatis project were very favourable, more than justifying the decision to address the topic of NoMix. We now have a more detailed appreciation of the advantages and disadvantages of the NoMix system.

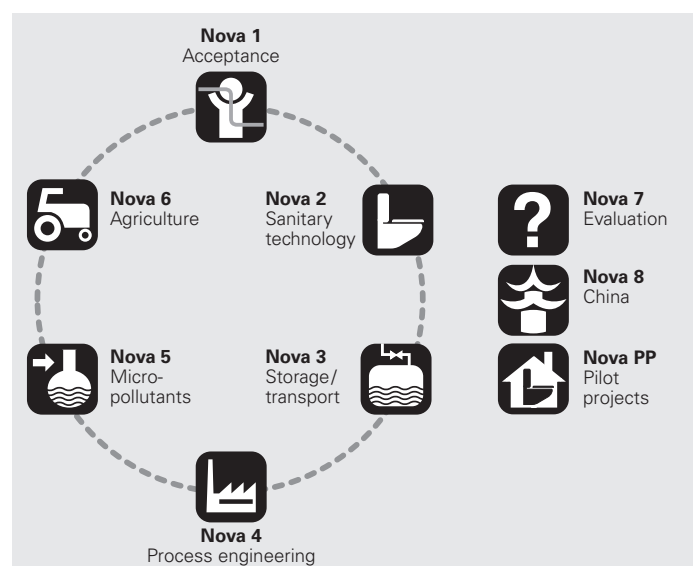
Nova 1: Acceptance. As the NoMix technology encroaches on private households, it requires the acceptance and approval of the general public. In the Nova 1 work package, we therefore examined the question of user attitudes. The main finding was that most respondents basically approve of the NoMix technology but do not wish to make any compromises on comfort in the long term. For more details, see the article by Judit Lienert on p. 8.

Nova 2: Sanitary Technology. Manufacturing NoMix toilets is a task for the sanitary industry. Today's appliances – only produced in small volumes – are not yet fully mature. One major problem is the blockage of pipes resulting from mineral deposits. In the Novaquatis project, we therefore established a close dialogue with the sanitary industry, feeding back our results concerning the development, extent and avoidance of precipitation (see the

article by Kai Udert on p. 11). It became clear that the sanitary industry will only become fully committed to improving NoMix toilets once an overall strategy and identifiable markets emerge. The first signs of a possible initial European market are now visible in the Netherlands, where around 20 pilot projects are being planned or have already been launched. These are a direct consequence of the stringent Dutch limits on nutrient emissions [2].

Nova 3: Storage and Transport. What proved to be the key problem for the NoMix technology is how to transport urine from households for centralized treatment. While this was not surprising, the perception was reinforced in particular by exchanges with the sanitary firms in Nova 2. Although various strategies for transporting urine through the existing sewer system were developed by Novaquatis [1, 3], they do not provide sufficient motivation for the sanitary industry to participate. This is because these trans-

Fig. 1: The nine Novaquatis work packages.



port concepts can only be applied in small catchment areas and under certain conditions.

Alternative approaches – transport by tanker or the laying of separate pipes for urine streams – appear unattractive, mainly on account of the expected costs. Decentralized urine treatment, e.g. on the same site, does however represent an attractive option. The promising nature of this scenario is shown by the results of Nova 4.

Nova 4: Process Engineering. Whether nutrients are to be eliminated or recovered as a fertilizer, we assume that, in an urban setting, urine will always have to undergo treatment. Firstly, transport and storage would otherwise hardly be manageable, and secondly fertilizers are subject to strict requirements in many countries. Research conducted in Nova 4 showed that numerous treatment processes are possible, and that in most cases they are also energy-efficient. This variety makes urine source separation extremely versatile: depending on the scenario, a wide range of goals can be achieved. An overview of the possible methods – many of which were developed in Eawag laboratories – is provided by Max Maurer in the article on p. 14. The specific combination of processes used to produce a urine-based fertilizer is described in the article by Wouter Pronk on p. 20. This is currently being tested in a pilot project involving a wastewater treatment plant in Canton Basel-Landschaft.

Nova 5: Micropollutants. As well as nutrients, dissolved organic compounds from the human metabolism are excreted via the kidneys. In Novaquatis, we focused on two important groups of substances of this kind – hormones and pharmaceuticals. These compounds are increasingly also being detected in waterbodies, and there is evidence to suggest that they are harmful to aquatic organisms. It therefore makes sense to remove these problematic micropollutants directly from urine, either in order to improve water pollution control or to avoid inputs to agriculture via a urine-based fertilizer.

For this reason, Eawag tested various methods of separating micropollutants, such as nanofiltration and electrodialysis (see the article by Wouter Pronk on p. 20). Moreover, methods for chemical detection of individual substances and for assessment of the ecotoxicological effects of pollutant mixtures were developed in Nova 5. This makes it possible to monitor the fate of micropollutants throughout the urine treatment process. This aspect is described in detail in the article by Beate Escher and Judit Lienert on p. 23.

Nova 6: Agriculture. An important role in the nutrient cycle is played by agriculture. Although we were unable to secure funding for this work package, significant results were obtained through collaboration with external scientific partners. An initial survey of attitudes among Swiss farmers revealed a willingness to use a urine-based fertilizer product. Hazards in relation to hygiene or micropollutants would, however, have to be excluded, and the fertilizer would have to be inexpensive (see the article by Judit Lienert on p. 8). In addition, fertilizer experiments with urine-



At Forum Chriesbach, urine is also separately collected from male and female users. The new Eawag headquarter building is fitted with NoMix toilets throughout.

based products from Nova 4 were carried out by the Research Institute of Organic Agriculture (FiBL) in Frick and the University of Bonn. The effectiveness of the urine-based fertilizers was shown to be comparable to that of conventional commercial products. For further details of these studies – and information on the requirements that a urine-based product has to meet if it is to be approved as a fertilizer in Switzerland – see the article by Markus Boller on p. 17.

Nova 7: Evaluation. Even after the completion of the Novaquatis project, definitive evaluation of the NoMix technology is not possible. It has, however, become clear that nutrient elimination is becoming increasingly important from a global perspective, particularly as a result of population growth and urbanization trends [4]. At the same time, the limitations of end-of-pipe measures (sewers and wastewater treatment plants) in densely populated areas are readily apparent (cf. the example of Kunming in the article by Tove Larsen et al. on p. 26). The NoMix technology could provide an energy-efficient means of reducing nutrient emissions in future [5]. If required, the nutrients can also be recycled to agriculture or industry – an option of particular relevance in the case of phosphorus. In view of the global freshwater scarcity, the NoMix technology could also offer advantages in regions where wastewater is to be directly reused after treatment, e.g. in South Africa. Here, separating urine from wastewater would make treatment considerably easier and improve the quality of the purified water.

Another important aspect is financing: on the assumption that the costs of wastewater treatment using the NoMix strategy are to remain the same as with today's conventional system, investments of approx. CHF 1250–2100 per household in Switzerland would be possible (including NoMix toilets as well as urine transport and treatment [6]). The NoMix technology would also provide significantly better performance with regard to nutrient elimination than the current system. Nonetheless, it is likely that



NASA

In fast-growing urban areas, wastewater disposal systems are frequently overstretched. The situation may be especially precarious in cities close to lakes or coastal waters. In such cases, the NoMix technology offers significant advantages. This was shown in a Novaquatis pilot project involving the Chinese city of Kunming (left), which has a population of several million and lies on the heavily eutrophicated Lake Dianchi (see article on p. 26) [7].

additional investments would initially be required if the NoMix technology was implemented. Savings would only arise when new wastewater treatment plants are built, as – with the NoMix strategy in place – they could be of smaller dimension and would thus be less expensive to be build and operate in the long term. This means that a well-organized transition from today's system to the NoMix technology is important.

Nova 8: China. In the past, the practice of urine source separation was widespread in rural areas of China. Considering the many environmental problems faced by China, it seemed reasonable to explore the opportunities offered by the NoMix technology in urban areas, too. In the article on p. 26, we report on our experiences in Kunming, Zurich's sister city in China. Even if the best available conventional technologies were applied at the local wastewater treatment plants, it would not be possible to protect the nearby Lake Dianchi from excessive inputs of phosphorus. By contrast, the potential of source control measures such as urine separation is enormous. For this reason, the NoMix concept is also supported by many Chinese experts. It is thus conceivable that the NoMix technology could be decisively boosted by the widespread introduction of urine-diverting toilets in China.

Nova PP: Pilot Projects. Our investigations would not have been nearly as successful if we had not had the opportunity to study urine source separation under real-life conditions in pilot projects (see the article by Markus Boller on p. 17). The large-scale projects in Canton Basel-Landschaft were especially important. Comparisons with pilot projects in other European countries such as Sweden, Germany, Austria or the Netherlands highlight the speed of developments in this area: the NoMix technology is increasingly viewed by practitioners as a realistic alternative to conventional nutrient elimination.

The Advantages of Nomix: Reducing Nutrient Emissions, Recovering Nutrients and Removing Micropollutants. Clearly emerging from the results of the Novaquatis project is a picture of an attractive technology – but one that still has to overcome numerous obstacles before it can actually be implemented. The environmental benefits are obvious: with the NoMix system, high standards for the reduction of nutrient emissions can be realized, and it becomes possible for wastewater treatment to be further developed in the direction of nutrient recycling and micropollutant elimination. It is true that, in Europe, all these goals could also be achieved with conventional strategies, if the necessary resources

NoMix: an Exportable Technology?

In a report issued in 2004, the United Nations Environment Programme (UNEP) warned that coastal fisheries in many regions were threatened by massive inputs of nutrients, and nitrogen in particular [8].

The nutrient issue was addressed by Novaquatis through its focus on urine source separation: urine accounts for up to 50% of the phosphorus and 80% of the nitrogen in domestic wastewater. From a global viewpoint, conventional wastewater treatment plants do not represent a realistic option for tackling the problem of nutrient overload rapidly and efficiently – but with urine source separation this goal becomes attainable.

In Europe, too, increasing demands are being placed on nitrogen elimination, and emission limits are likely to be tightened in the future. In the Netherlands, the water pollution control authorities are currently investigating whether urine source separation would enable limits to be complied with at a lower cost than is possible with conventional wastewater treatment technology [2].

In the Novaquatis project, we were mainly concerned with the situation in Switzerland, as we have experience in this country and wished to evaluate urine source separation for modern cities. However, in the meantime the pressing nature of this issue at the international level has become clearer. In Novaquatis follow-up projects, we will therefore be placing greater emphasis on the global aspect. On the basis of our results to date, it would appear logical to take action initially in areas where the NoMix technology can be expected to produce dramatic improvements within a short period, e.g. in fast-growing coastal cities.

were committed. But the stricter the limits for nutrients, the more expensive wastewater treatment becomes – until a point is reached where efforts to rehabilitate a waterbody are abandoned for reasons of cost. In Switzerland, an example of this kind is Lake Greifen.

The challenge for NoMix technology is thus to provide an *inexpensive* solution that replaces or complements the role played by traditional nutrient elimination processes at wastewater treatment plants. At the same time, such a solution should keep open the additional options of urine source separation, nutrient recycling and efficient removal of micropollutants.

The Future for NoMix: Development of Decentralized Solutions. The results of the Novaquatis project clearly suggest the

steps that need to be taken next: either a suitable option for urine transport will have to be found, or urine will have to be treated close to where it arises – ideally in an apartment block or even in a single-family home. Identifying suitable transport options is a difficult task and does not fall within the scope of Eawag's traditional research activities. In contrast, Eawag is well suited for the task of developing decentralized treatment solutions. These would involve low-cost and low-maintenance technical processes and equipment. At the same time, solutions would also be required on the organizational level: how is it to be assured that the equipment is correctly used and maintained, and that any malfunctions are reported and rectified in good time?

If the NoMix technology is to be implemented at low cost, large markets will be required so as to permit mass production. Within the Novaquatis project, we have come to the conclusion that use of the NoMix technology would be appropriate in many areas, especially where populations are growing fast, e.g. in coastal regions. We are therefore confident that suitable initial markets can be identified.

The scientific challenges involved in the elaboration of decentralized solutions are enormous, both from a technological and from a socioeconomic perspective. However, we believe that the interdisciplinary environment at Eawag facilitates developments of this kind, and we are now considering in detail whether or not to take on this challenge in the years ahead. ○ ○ ○

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Judit Lienert, biologist and Novaquatis project manager

A Good Idea, but Surely No Takers!

Right? No, wrong! According to our studies of user attitudes in pilot projects involving public buildings and private households, and among farmers, many people approve of NoMix toilets and urine-based fertilizers. However, NoMix toilets have a number of weak points which would need to be remedied by the sanitary industry before large-scale implementation can be recommended.

The innovation “NoMix technology” is not being tested out of sight at wastewater treatment plants, but in private bathrooms. For this reason, people’s initial reaction to urine separation is often: “It’s a good idea, but nobody would want a NoMix toilet!” When it is explained that urine is recycled to produce fertilizers, they may object: “Farmers are opposed to the idea, and nobody would buy the vegetables.” Our aim was to find out precisely what the public thinks of NoMix toilets and urine-based fertilizers.

Are NoMix Toilets Accepted in Public Buildings? In Switzerland, NoMix toilets have already been installed in several public buildings. We therefore conducted a survey of 1249 users of these facilities at a vocational college and at Eawag. In both cases, acceptance levels were very high: 72% liked the idea of urine source separation, and 86% would move into an apartment fitted with a NoMix toilet [1]. For the majority of respondents, the NoMix system was equivalent to a conventional toilet with regard to design, hygiene and odour (Fig. 1). In most cases, behaviour

was adapted to the requirements of the NoMix toilet: 72% sat to urinate and 58% disposed of toilet paper in a separate bin. This resulted in a saving of 84 litres of water per 100 usages (as calculated in [1]).

Marked differences were, however, observed between user groups. For example, the hygiene and odour of NoMix toilets were rated as poorer than for conventional toilets by, respectively, 32% and 50% of Eawag staff, but only 17% of Eawag visitors. We suspect that the Eawag staff may have been influenced by unhappy memories: they recalled the unpleasant odours in the bathrooms associated with technical hitches involving the urine tank and maintenance of the waterfree urinals.

If acceptance and behavioural adaptations are to be promoted, clean toilets are an essential requirement. However, it was also

Fig. 1: Assessment of NoMix toilet design, hygiene and odour by 534 users at a vocational school and 715 people at Eawag [1].
Blue: NoMix better than a conventional toilet; yellow: both the same; orange: NoMix toilet inferior.

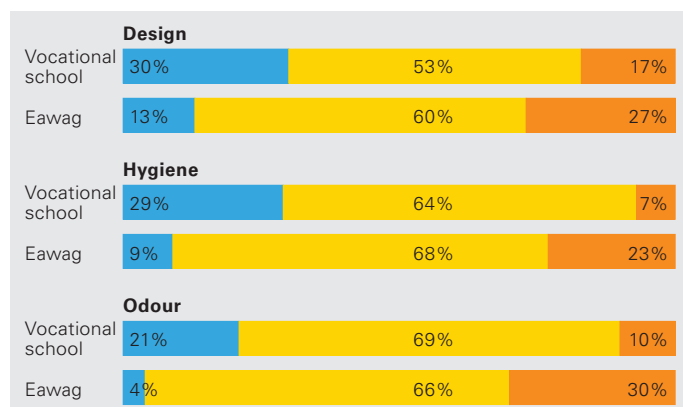
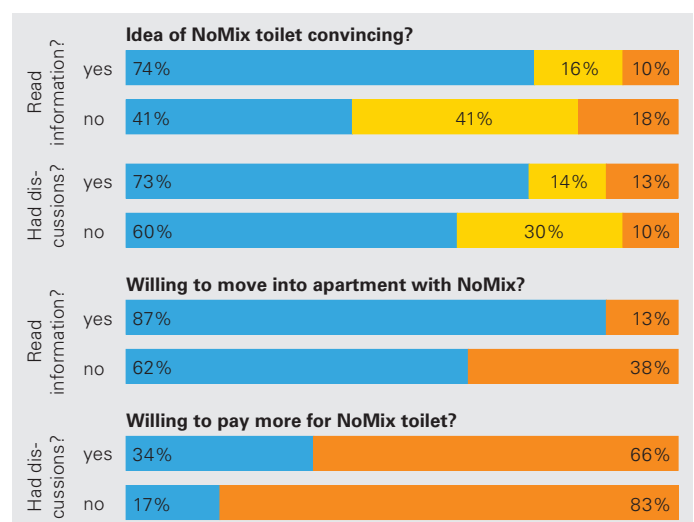


Fig. 2: Correlation between acceptance of the NoMix toilet and how well informed users are about the NoMix technology [1]. 480 respondents at a vocational school and at Eawag were asked whether they had read our information material and discussed the NoMix toilet with other people. Blue: yes; yellow: don't know; orange: no.





Ruedi Keller, Zurich

“Are you satisfied with the NoMix toilet?” A survey of Eawag staff.

noted that acceptance, behaviour and perceptions can be influenced by sound communication and by discussions with other people (Fig. 2).

These findings are confirmed by a representative survey conducted on our behalf at the Basel-Landschaft Cantonal Library in Liestal, which involved 501 users (study not yet published). This building is fitted exclusively with NoMix toilets.

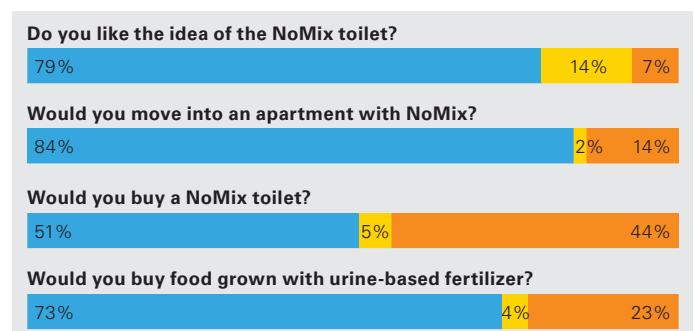
Would the Swiss Use NoMix Toilets at Home? Initial evidence suggesting that NoMix toilets would also be acceptable in private households under certain conditions was provided by a citizen focus group study involving 44 volunteers (Fig. 3) [2]. The participants had first familiarized themselves with the idea of urine source separation using an interactive computer tool [3] and visited a NoMix toilet at Eawag. One important point discussed was the increased need for maintenance arising from the fact that precipitation of the salts in urine leads to clogging of drainage pipes (cf. article by Kai Udert on p. 11) [4]. Most people would be deterred by this problem.

Research was taken a step further with the installation of NoMix toilets in four private apartments. The residents’ reactions varied widely: while some were sceptical, others approved of the NoMix toilet on environmental grounds and found its use unproblematic. Several residents noted that increased cleaning efforts were required. Other objections raised were that some men would not sit down or that the sitting position was uncomfortable. Children in particular found it difficult to aim correctly, leading to a greater need for cleaning (this was also the case in public buildings). These findings would need to be supplemented by studies on a broader scale, but this is not possible in Switzerland due to the lack of large implementation projects involving private households.

What is the Situation in Other Countries? Across Europe, a number of NoMix pilot projects – some on a relatively large scale – have been carried out in private households. In Sweden, more than 135,000 urine-diverting toilets have been installed since 1990 – mostly very simple systems for remote holiday homes [5]; thousands of NoMix toilets have also been installed in eco-villages and municipal pilot projects. Pilot projects are increasingly being conducted in the Netherlands, Austria and Germany. Urine source separation is also an attractive option for fast-industrializing countries such as China (cf. article by Tove Larsen on p. 26).

In 2003, 88 apartments and a school in the Austrian city of Linz were fitted with NoMix toilets [6]. These were rated as less comfortable to use than conventional toilets by around 50% of the residents. Nonetheless, 69% of the men frequently or exclusively sat to use these toilets. Additional cleaning efforts were reported by about 65%, which also matches our own findings. Overall, a third of the respondents were very, a third moderately and a third

Fig. 3: Views of 44 focus group participants on the NoMix technology [2]. Blue: yes; yellow: don’t know; orange: no.



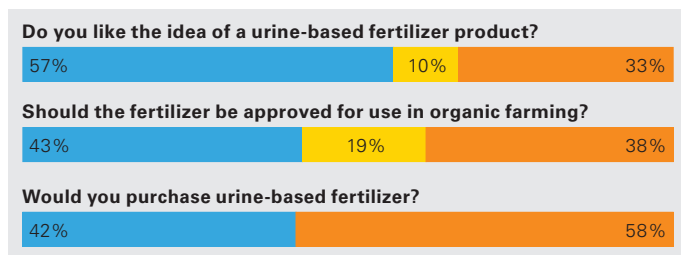


Fig. 4. Views of Swiss-German farmers on urine-based fertilizer [8]. Questionnaires were sent to 467 farms, and responses were received from 127. Blue: yes; yellow: don't know; orange: no.

not satisfied with the NoMix toilet. Half would change back to conventional toilets if they could.

As in Switzerland, project managers in Austria and Sweden [7] noted that levels of acceptance and motivation to use the NoMix toilet in a seated position were higher when people were well informed and appreciated the (environmental) benefits of the entire scheme.

Would Farmers and Consumers Accept Urine-based Fertilizers?

The idea of recycling urine to produce a fertilizer was surprisingly well received by farmers (Fig. 4), whose attitudes were studied via a mail survey [8]. The farmers attached the greatest importance to the absence of micropollutants: 30% of the respondents were concerned that the fertilizer could contain residues of pharmaceuticals and hormones.

Consumers' attitudes appear to be even more favourable, provided that health hazards can be ruled out. A majority of those surveyed in the focus groups (Fig. 3) and at the Cantonal Library in Liestal would be willing to purchase food grown with urine-based fertilizers. A majority of the 501 respondents at the Cantonal Library would also use a urine-based product on their own balcony or in the garden. However, just under a third of this group was opposed to urine-based fertilizers, mainly because they aroused disgust and might contain pharmaceuticals or pathogens.

Few comparable studies are available internationally. In Sweden, urine-based fertilizers were well accepted. Here, urine was stored for purposes of hygienization, but not treated. In most cases, a farmer was prepared to spread the urine, or it was used by residents in their own garden. The odour was rarely found to be troublesome during application of the fertilizer, and hardly any concerns were expressed about consuming urine-fertilized vegetables [7].

Next Steps. We now know that the public has very positive attitudes towards the NoMix technology. However, NoMix toilets have certain drawbacks which may be problematic in everyday use. The introduction of NoMix toilets in private households is therefore a delicate enterprise, which has to be managed extremely carefully. Household users need to be aware of possible drawbacks from the outset and should give an undertaking that they will accept these [4]. Direct contact with the residents

is very important, to ensure that problems can be addressed immediately. The installation of NoMix toilets in public buildings is less problematic – if cleaning and maintenance are carried out by internal staff.

The dilemma we now face is that further development of the NoMix technology requires large-scale pilot projects, but NoMix toilets are not yet fully comparable to conventional toilets. Widespread introduction of an immature technology can lead to a backlash, destroying its prospects altogether. If the technology is to be advanced, the sanitary sector would need to improve the NoMix toilets. But large companies are reluctant to make major investments in the absence of a potential market. Accordingly, wastewater professionals, as well as authorities, developers and policymakers, need to demonstrate to the sanitary industry that genuine interest exists in this technology [9]. Since the public is willing to contribute to the development of this innovation, we take the view that – even with today's imperfect NoMix toilets – the process of implementation can be launched, provided that such pilot projects are carefully supervised. ○ ○ ○

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NoMix Begins in the Bathroom



Kai Udert, environmental engineer and research associate in the Environmental Engineering Department

The basic idea of the NoMix toilet is simple: urine is drained – separately from other wastewater – into a collection tank. However, urine pipes can easily be blocked by mineral precipitates, and nutrient concentrations in the urine collected may be lower than expected. The results of our laboratory experiments and computer simulations should facilitate the development of improved appliances in collaboration with the sanitary technology sector.

Fresh urine is an unstable solution. The urea component is already broken down in siphons and pipes, leading to the formation of phosphate, magnesium and calcium precipitates that block urine drains. The flushing of the toilet reduces the risk of blockages, but the resultant dilution of urine makes large storage tanks necessary and complicates further treatment. The development of NoMix appliances that can collect urine in a highly concentrated form without being prone to blockages represents a challenge for the sanitary industry.

To provide a basis for further refinement of the sanitary systems, we carried out detailed studies of the processes occurring in NoMix appliances: we investigated the formation and composition of precipitates and how precipitation can be prevented. At the same time, we sought to explain why the composition of urine stored in the collection tank differs markedly from the values that would have been expected on the basis of literature data concerning fresh urine [1–3].

Formation and Composition of Precipitates. Our laboratory experiments showed that precipitation is ultimately attributable to hydrolysis of the urea contained in urine. Urea is converted by microorganisms found in toilets and urine pipes into ammonia and carbonic acid, raising the pH of the urine to a level of about 9 (Fig. 1A). In turn, this high pH leads to supersaturation of several minerals, which finally precipitate: struvite ($\text{MgNH}_4\text{PO}_4 \cdot 6 \text{H}_2\text{O}$) and hydroxyapatite ($\text{Ca}_5(\text{PO}_4)_3\text{OH}$), as well as calcite (CaCO_3) (Fig. 1B), if the solution is highly diluted with flushing water [2]. Using computer simulations, we calculated that only 8% of the urea in undiluted urine needs to be hydrolysed to allow pH values sufficiently high for 95% of the precipitation potential to be attained. While the precipitates formed can block pipes and siphons, they do not cause problems in the collection tank, where they do not dry out and therefore cannot solidify.

The Higher the Dilution, the Lower the Risk of Blockages. Urine-diverting toilets are designed to collect urine without it being mixed with flushing water. However, as we concluded from our

field studies, NoMix pipes are especially likely to become clogged when the urine is scarcely or not diluted at all (Fig. 2). This finding contradicts the conventional view that blockages will only occur if urine is mixed with water – since water provides the cations (calcium and magnesium) that are required for precipitation. In fact, urine already contains more calcium and magnesium than normal tap water. According to our calculations, while 1400 mg of salts are crystallized from a litre of undiluted urine, the salts precipitated from a litre of urine diluted in the ratio 1:1 amount to approx. 900 mg [2]. The quantity of precipitates per unit volume is one of the most important factors (although not the only one) contributing to the risk of blockages. Other critical factors include prolonged residence times of urine in pipes and siphons, and narrow cross-sections. These findings suggest a variety of measures that can be adopted in order to prevent or at least delay the onset of blockages [1]. Given the current state of technology, the following measures are to be recommended:

NoMix urine pipes are prone to blockages.



Kai Udert, Eawag

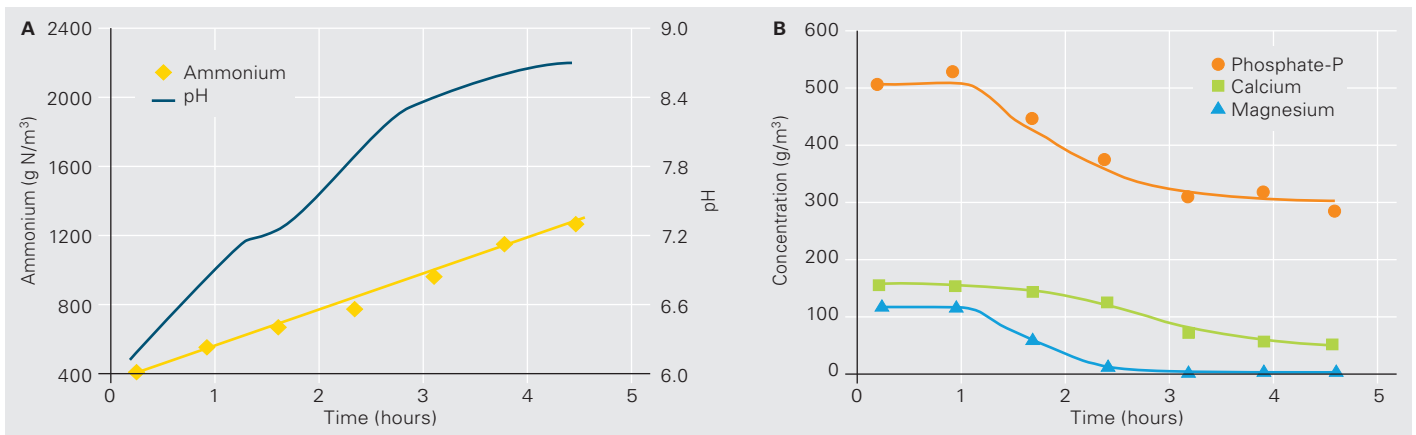


Fig.1: Due to the hydrolysis of urea in the urine, ammonium concentration and pH increase (A) while the concentrations of calcium, magnesium and phosphate decrease (B).

- ▶ Use of acids at regular intervals to dissolve and flush precipitates out of the system (e. g. 10% citric acid).
- ▶ Controlled precipitation in large siphons (standard practice, e. g. for water-free urinals).
- ▶ Use of rainwater rather than tap water for flushing.
- ▶ Use of pipes with larger diameters.
- ▶ Ensuring that urine passes through narrow sections as rapidly as possible, e. g. by vertical arrangement of pipes.
- ▶ Additional measures are conceivable, but would require development and testing, e. g. pipe coatings that repel bacteria or solids.

Nutrient Concentrations in Urine. The technical characteristics of NoMix sanitary facilities have a significant influence on the composition of the urine collected. To facilitate further processing, it is desirable for the concentrations to be as high as possible.

This applies in particular to the nutrients phosphorus and nitrogen. However, in none of the pilot projects carried out to date have the concentrations expected for undiluted urine actually been obtained (see the article by Max Maurer on p. 14). Concentrations of nitrogen and phosphorus in stored urine were, respectively, 1.5–5 and 2–10 times lower than the values given in the literature for fresh urine [3, 9, 10]. This is due to a number of different factors. Concentrations of both nutrients are equally reduced by dilution with flushing water. As a result of the precipitation associated with urea hydrolysis, a large fraction of the soluble phosphate is eliminated from the urine [2]. If the tanks and pipes are ventilated, part of the nitrogen content is released as ammonia, also as a result of ureolysis. In public facilities, lower concentrations can also be explained by the absence of highly concentrated early-morning urine.

NoMix Toilets and Water-free Urinals: Collecting Urine and Saving Water

In many cultures, separate collection of urine and faeces was practised for centuries, and it is still routine in a number of developing and fast-industrializing countries. However, the first water-flushed urine-diverting toilets were developed in Sweden in the 1990s. Today, NoMix toilets are available from several small companies. The models used in the Novaquatis pilot project were produced by four different manufacturers: Wost Man Ecology [4], Dubbletten [5], Gustavsberg [6] and Roediger [7]. While they all have separate outlets for urine and other wastewater, they differ in the way the flush operates. In most models, the flushing water is distributed across the entire bowl, so that water enters the urine drain each time the toilet is flushed. The Roediger toilet uses a different system, however: it incorporates a valve which is only opened when someone sits on the toilet seat. When the user stands up and activates the flush, the valve is shut, and the urine is thus collected practically undi-

luted. Although Dubbletten also seeks to keep urine dilution to a minimum, its system employs a fundamentally different principle: urine and other wastewater are collected in two separate bowls, flushed by different mechanisms. The amount of flushing water entering the collection tank with the urine can thus be minimized. In most of the Novaquatis pilot projects, water-free urinals were used as well. Unlike NoMix toilets, these have long been available from numerous suppliers and are widely used in public buildings, mainly on account of their water-saving features. Water can also be conserved with Dubbletten-type NoMix toilets, although this is only possible if urine-soiled toilet paper is not flushed away, but disposed of separately in a bin. A survey conducted at Eawag showed that 58% of people using the Dubbletten toilets installed at this site actually modified their behaviour accordingly [8].

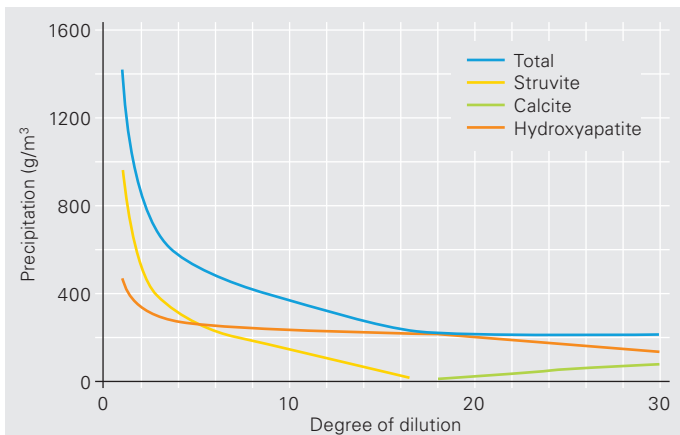


Fig.2: Precipitation of struvite, hydroxyapatite and calcite depends on the degree of urine dilution.

Need for Further Development of NoMix Toilets. At present, NoMix toilets are only manufactured in small quantities by a handful of suppliers. Product development is therefore very sluggish, which in turn impedes the spread of this technology. Our initial experience from the Novaquatis pilot projects has already been fed back into the development of the Roediger NoMix toilet. This input was mainly based on reports from users (see the article by Judit Lienert on p. 8). Among the points criticized were the increased cleaning efforts required, the need to sit down to use

the toilet, and the positioning of the two outlets. Odour problems were also reported; however, it is possible that the odour nuisance was not due to the NoMix toilets but arose from insufficient cleaning of the nearby water-free urinals.

In addition, to give further momentum to the development process, representatives of the sanitary and wastewater sectors were invited to participate in round-table talks chaired by Novaquatis. These discussions focused on what is required to bring an optimized NoMix toilet onto the market. It transpired that sanitary firms wish to have large, well-defined initial markets to which they can gear the development of the NoMix toilet. Such markets are to be found in particular in areas facing urban drainage and water pollution control problems – i.e. in the rapidly expanding cities of fast-industrializing countries. But regions of water scarcity, e.g. in Australia, may also provide a market for NoMix technology. It should be noted, however, that the strategy pursued by Novaquatis – involving gradual introduction of the technology in cities with existing sewerage systems – is less attractive to the industry, as the market is thought to be too small. Another factor of prime importance to the sanitary industry is the attitude of wastewater professionals. If they regarded NoMix technology as valuable and supported its introduction, this would also have a stimulating effect on the sanitary sector.

Nonetheless, the sanitary industry remains fundamentally interested – and convinced that the problems of today's NoMix appliances can be resolved. It goes without saying that development of this kind has its price. ○ ○ ○

Vertical urine pipes with large cross-sections reduce the risk of blockages.



Kai Udert, Eawag

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Urine Treatment – Absolute Flexibility



Max Maurer, chemical and process engineer in the Environmental Engineering Department

What happens to urine after it has been collected? The particular characteristics of this liquid permit a wide range of treatment methods. These can be used to modify the unusual resource as required – e. g. to remove specific pollutants or to produce a fertilizer. The suitability of a number of processes has been assessed by Eawag.

NoMix technology allows separate treatment of urine. However, customized processes have to be developed to treat this special liquid (Tab. 1 and Box). Our aim was therefore to identify methods that could be applied in practice. For this purpose, we performed a literature search for procedures that had previously been used in connection with urine. In addition, further processes were tested in Eawag laboratories to determine their suitability for urine treatment. Our studies yielded a broad range of methods for hygienization and stabilization, for the removal and inactivation of organic micropollutants, and for the recovery and elimination of nutrients (Tab. 2; for details see [1]). While these procedures ensure a high degree of flexibility in urine treatment, it will usually be necessary – depending on the specific aims of urine source separation – to combine various methods within a treatment unit (see also the article by Wouter Pronk on p. 20).

Hygienization Through Urine Storage. Collected urine may contain pathogenic organisms, deriving either from patients or from contamination with faeces. The simplest way of hygienizing urine is to store it for a period of several months. The crucial factor in this process is the storage temperature. Tests have shown that storage of urine at 20 °C for 6 months is sufficient to obtain a perfectly hygienic state. Although numerous other treatment options exist, such as exposure to ultraviolet light or high-pressure processing, they have never been tested on urine.

Stabilization with Acid or Biological Treatment. In certain cases, urine should be stabilized prior to further treatment. This allows labile substances in the urine to be preserved or eliminated so as to prevent unpleasant odours and environmental impacts from toxic ammonia emissions.

Fresh urine can be preserved by the addition of a strong acid, e. g. 2.9 g/l of concentrated sulphuric acid, since urine is stable below pH 4. This method of preparation is also used when water is to be recovered from urine on lengthy space missions. By contrast, sterile filtration – another method that we tested – proved not to be suitable in practice because the enzymes responsible for decomposition are present in dissolved form in urine, and were still able to pass through the filter.

Alternatively, urine that is already decomposed can be stabilized by means of biological treatment. Our experience with this approach involved a variety of bioreactor configurations. In this process, the readily degradable organic substances are broken down by bacteria and, in addition, through nitrification (conversion of ammonia to nitrite and nitrate by aerobic bacteria), the pH of the urine is lowered and volatile ammonia is removed. The extent of nitrification varies according to the reactor configuration, and an odourless ammonium nitrate or ammonium nitrite solution is obtained.

The nitrate solution could subsequently be used as a rapidly acting liquid fertilizer, while the nitrite solution could be processed further in an anaerobic ammonium oxidation reactor. In the so-called anammox reaction, ammonium is converted to molecular

Tab. 1: Chemical composition of collected, stored urine from a household with water-flushed urine diverting toilets [2] and from the Eawag office building with water-free urinals [3], compared with fresh urine [4]. COD = chemical oxygen demand, a measure of the organic components.

	Stored urine		Fresh urine Undiluted Literature data
	With flushing water Household	Without flushing water Office building	
Dilution $V_{\text{urine}} / (V_{\text{urine}} + V_{\text{water}})$	0.33	1	1
pH	9.0	9.1	6.2
N_{total} (g/m ³)	1795	9200	8830
$NH_4^+ + NH_3$ (g N/m ³)	1691	8100	463
$NO_3^- + NO_2^-$ (g N/m ³)	0.06	0	–
P_{Gesamt} (g/m ³)	210	540	800–2000
CSB (g O ₂ /m ³)	–	10000	–
K (g/m ³)	875	2200	2737
Na (g/m ³)	982	2600	3450
Cl (g/m ³)	2500	3800	4970
Ca (g/m ³)	15.75	0	233
Mg (g/m ³)	1.63	0	119

Urine, a Special Liquid

Urine that is collected and stored for a prolonged period differs considerably from the original solution (Tab. 1). It develops a pungent odour of ammonia, and the pH increases from 6 to more than 9. Both of these changes are a result of the bacterial hydrolysis of urea, which produces ammonia and carbon dioxide. The chemical composition is also influenced by the amount of flushing water in the collection system.

Particularly striking are the high concentrations of nutrients in undiluted urine. Compared with normal wastewater, the concentrations of total nitrogen and total phosphate are about 200 and 100 times higher, respectively, and the chemical oxygen

demand is approx. 30 times greater. If fresh and stored urine are compared, the transformations occurring during storage are clearly evident. The content of inorganic nitrogen ($\text{NH}_4^+ + \text{NH}_3$) and the pH are increased as a result of urea hydrolysis. This also leads to a reduction in the concentrations of calcium (Ca), magnesium (Mg) and phosphate, which are deposited as solids in the tank or pipes (see the article by Kai Udert on p. 11).

While scarcely any heavy metals are found in human urine, many medicines and hormones are excreted via the kidneys (see the article by Beate Escher on p. 23).

nitrogen under anaerobic conditions with the aid of nitrite. Both liquids may also be used to combat odours and corrosion in the sewer system.

Micropollutants Destroyed or Inactivated by Ozonation. The most reliable method of eliminating micropollutants has proved to be ozonation. Although the pollutants may not be completely broken down by this process, they are largely inactivated. If micropollutants are to be removed from a specific product, such as a fertilizer, nanofiltration or electrodialysis can also be used (for details see the article by Wouter Pronk on p. 20). Since it appears that not all micropollutants are degradable in bioreactors, combination with ozonation needs to be considered so as to ensure that the micropollutants are largely eliminated. In our studies, the

substances propranolol (beta-blocker), ibuprofen (anti-inflammatory agent) and ethinyl estradiol (synthetic hormone) were poorly degraded, whereas the natural hormones estradiol and estrone were very effectively eliminated.

Nutrient Recovery Through Evaporation and Stripping. The composition of urine makes it a good multicomponent fertilizer. The nitrogen-phosphorus-potassium (NPK) ratio is approx. 100:6:25 (Tab. 1) or, using the standard fertilizer nomenclature, $\text{N}:\text{P}_2\text{O}_5:\text{K}_2\text{O} = 0.9:0.12:0.26$ (percentage by weight). There are various ways in which the nutrients can be further concentrated, or individual nutrients recovered:

► Volume reduction: this process facilitates storage, transport and dosing. Technically the most mature method is evaporation.

Tab. 2: Possible methods for urine treatment [1]. o = no effect, + = positive effect, ++ = strong effect, ? = effect possible, but not studied.

	Hygienization	Volume reduction	Stabilization	Nutrient recycling	Degradation/inactivation micropollutants	Separation nutrients – micropollutants	Nutrient elimination
Hygienization							
Storage	+	o	o	o	o	o	o
Stabilization							
Acidification	+	o	++	o	?	o	o
Sterile filtration	+	o	++	o	o	o	o
Nitrification	+	o	++	o	?	o	o
Nutrient recycling							
Volume reduction, e.g. Evaporation	+	++	+	++	o	o	o
Struvite precipitation	o	++	+	++ (esp. P)	o	++	o
Selective adsorption	o	+	o	++ (only N)	o	+	o
NH_3 stripping	o	+	o	++ (only N)	o	++	o
Nutrient elimination							
Anammox	+	o	++	o	?	+	++
Elimination of micropollutant							
Electrodialysis	++	+	+	+	o	+	o
Nanofiltration	++	o	+	o	o	++	o
Ozonation	+	o	+	o	++	o	o

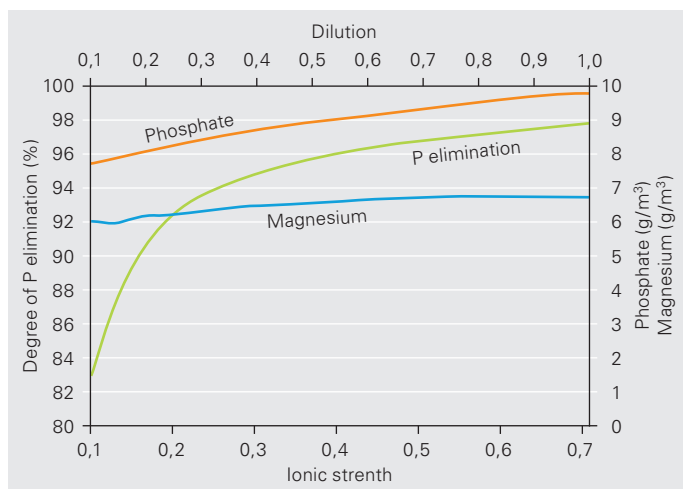


Fig. 1: The soluble phosphate and magnesium concentrations after struvite precipitation depend on the degree of dilution with flushing water (1 = undiluted, 0.1 = 10-fold dilution). Initial concentrations of nutrients in undiluted urine: phosphate = 440 g P/m³; ammonium = 7850 g N/m³. An equimolar quantity of magnesium chloride is added (based on phosphate).

This is also used on a small scale in space stations. In our tests carried out at 200 mbar and 78 °C with non-hydrolysed urine (see Box), it was a simple matter to reduce the volume by a factor of 10. In another method, known as partial freezing, urine is frozen to such an extent that one fraction remains liquid. This liquid phase contains the bulk of the nutrients, whereas the ice consists mainly of water.

► Stripping: ammonia is stripped out of the urine, e.g. by means of an air stream, producing an ammonia or ammonium sulphate solution. Both products can be used either as starting materials or as fertilizers.

Nutrient Recovery by Struvite Precipitation and Selective Adsorption.

Struvite (i.e. magnesium ammonium phosphate, MgNH₄PO₄, or MAP) is a well-established slow-acting multicomponent fertilizer. Our laboratory studies showed that this compound can also be produced from urine. Struvite forms spontaneously as soon as magnesium is added to urine, e.g. in the form of magnesium oxide or magnesium chloride. The reaction is rapid and complete. The more urine is diluted with flushing water, the lower the yield of struvite (Fig. 1). To a certain extent, this can be offset by markedly increasing the quantity of magnesium added. With struvite precipitation, 96–98% of the phosphorus content can be recovered from urine [5].

We also showed that the pharmaceuticals and hormones studied remained entirely in solution and were not detectable in the end product. No more than 20–40% of any heavy metals contained in urine are precipitated with the struvite [6]. Struvite precipitation is thus a simple and effective method for recovering nutrients – free of pollutants – from wastewater streams.

Nutrients can also be obtained from urine by selective adsorption. An attractive option is the use of zeolite. If this mineral is

added to urine, it adsorbs nitrogen and can subsequently be used as a nitrogen-containing soil conditioner.

Nutrient Elimination. If the ultimate goal of urine treatment is to improve water pollution control, the aim may be to remove nitrogen and phosphorus from urine without subsequently recycling these nutrients. Given the particular characteristics of urine, the anammox process described above can be used in addition to the methods usually applied for wastewater treatment.

Range of Processing Options Available for Urine Treatment.

Numerous methods are suitable for the treatment of separately collected urine. Therefore, process engineering will certainly not be a limiting factor for the implementation of urine source separation in practice. At the same time, most of these methods are still at the laboratory stage. Practical experience is rare, and major gaps remain to be filled, especially in the development of reliable small-scale processing units for decentralized use.

The variety of possible urine treatment methods shows that source control measures such as urine separation, provide increased flexibility for wastewater management. The foundations have been laid for further development, and the time has now come for the transition to practical application. ○ ○ ○

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Fertilizer from the Library

Producing a hazard-free fertilizer from urine is a new concept. Initial experience is being gained at the Basel-Landschaft Cantonal Library in Liestal, which is fitted exclusively with NoMix toilets. The urine collected at this institution is processed to yield a liquid fertilizer. But before the product can be applied, a number of obstacles need to be overcome. Similar challenges also face pilot projects in other countries.

One of the goals of urine source separation is to recycle nitrogen, phosphorus and potassium to agriculture. These nutrients excreted by humans derive from foodstuffs. The increasing scarcity of nutrients makes it essential for substances used as fertilizers to be sustainably managed – especially in the case of phosphorus since, at current rates of extraction, natural reserves of this mineral will be exhausted in 50–100 years. Existing practice – whereby nutrients are released via wastewater treatment plants into receiving waters, air and sludge and thus irretrievably “disposed of” – needs to be transformed, with the aim of reusing valuable nutrients as comprehensively as possible; this would reflect the age-old use of animal excreta. However, from today’s perspective, a wide variety of obstacles will first have to be surmounted. If the idea is to be implemented in practice, it must be shown to be politically, technically, environmentally and economically compelling.

The urine-based product Urevit is applied to a maize field.



Photos: Martin Koller, FIBL



Markus Boller, engineer, head of the Urban Water Management Department and Professor at ETH Zurich, where he lectures in water supply and wastewater treatment

Elimination of Micropollutants from Urine-based Fertilizer.

According to our studies, society is essentially open to the NoMix technology. A majority of the public is prepared to accept urine-diverting toilets [1], and Swiss farmers can envisage using a fertilizer produced from urine [2] (see the article by Judit Lienert on p. 8). The product would, however, have to be of high quality, inexpensive, hygienically safe and free of micropollutants such as pharmaceuticals and hormones. Agricultural regulators also expect a urine-based fertilizer to meet stringent requirements. The approval procedure established by the authorities calls not only for proof of effectiveness, but also for experimental evidence of the absence of micropollutants. Experience from the debate on the quality of sewage sludge shows that, politically, the use of untreated urine in Switzerland would not be feasible. The removal of hazardous micropollutants is thus a prerequisite, even if this substantially increases the technical complexity of urine processing.

Breaking New Ground in Process Engineering. To initiate the approval process and to demonstrate that it is technically possible to produce a safe fertilizer from urine, Eawag launched a urine treatment pilot project at the Birs I wastewater treatment plant (WWTP) in Birsfelden (Canton Basel-Landschaft). Here, engineering processes developed at Eawag are used to produce a liquid fertilizer from urine under real-world conditions. The urine used comes from the newly built Cantonal Library in Liestal, which – thanks to the favourable attitude of Basel’s policymakers and the authorities responsible – is fitted throughout with NoMix toilets and water-free urinals. Since the opening of the building in June 2005, urine from up to approx. 4000 library users per week has been available for fertilizer production at the Birs I WWTP.

When urine is processed to produce a fertilizer, the achievement of four goals needs to be assured:

- ▶ The nutrients nitrogen, phosphorus and potassium are to be concentrated.
- ▶ Micropollutants such as hormones and pharmaceuticals are to be largely eliminated.

Location	No. of NoMix toilets	No. of water-free urinals	Urine volume arising (l/week)	Urine tank size (m ³)	Urine treatment	Application, reuse
GTZ Eschborn D	56	25	8000	10	Struvite precipitation, NH ₃ -stripping	Effectiveness testing, field trials
Huber D	13	10	550	0.9	Struvite precipitation, ammonium sulphate precipitation	Crop fertilizers
Lambertsmühle D	4	2	60	4	None	Agriculture
Linz A Apartments School	88 18	12	approx. 2500 approx. 1500	16 6	None	Sewer system
Gebers S	25	0	approx. 700	3x3.5	Storage for 6 months	Agriculture
Understenshöjden S	50	0	approx. 1000		Storage for 6 months	Agriculture
Basel-Landschaft Cantonal Library CH	10	2	100	1.7	Electrodialysis, ozonation	Effectiveness testing
Eawag CH	39	7	250	1 in each case (men + women)	Biological methods	Research: development of additional treatment methods

Tab. 1: National and international urine source separation projects.

- The product must be hygienically acceptable.
- The urine is to be stored in a stable form as a urea or ammonium solution.

From the wide variety of – in most cases – technically demanding processes available [3] (see also the article by Max Maurer on p. 14), a combination of electrodialysis and ozonation was chosen for the urine treatment plant at the Birs I WWTP. Both of these methods – neither of which has previously been applied in municipal wastewater treatment – were developed to the point of technical maturity at the Eawag laboratories and are now being tested on a large scale for the first time in our pilot project. Details of the functioning and operation of the pilot plant are given in the article by Wouter Pronk on p. 20 [4]. The main aim of this pilot study is to provide an example of how possible technical options for closing nutrient cycles can be put into practice and, in a real-life test to demonstrate the potential of nutrient recovery from urine both to the experts and authorities concerned and to interested members of the public. The results achieved to date are encouraging and should pave the way for the adoption of alternative wastewater management processes.

Urine Separation in Other Countries. From an international viewpoint, Eawag is not alone in its efforts to remodel nutrient cycles in developed areas. For some years, numerous activities have been under way, notably in Sweden, Germany, Austria and the Netherlands (Tab. 1). These include a number of projects described in detail in the literature, involving use of the NoMix technology on a large scale. Initially, the solutions adopted – often designed for rural areas – assumed that there were no grounds for concern with regard to urine quality, which meant that the urine could be used simply and directly. In the meantime, however, the issue of micropollutants in urine has been widely discussed. For example, recent tests with unpurified, concentrated urine applied

as a fertilizer in high doses showed that the unwanted substances accumulate in the soil and in plants, inhibiting crop growth [5]. The hazard posed by micropollutants should therefore not be underestimated and is currently shaping development efforts in the area of urine storage and treatment. Likewise, research is increasingly focusing on the quality of the different types of product arising, with regard to fertilizer properties in agriculture.

Various projects in Sweden have shown that utilization of the urine collected is a crucial factor motivating the installation and continued use of urine-diverting toilets. For example, the NoMix toilets originally installed in the ecovillage of Björnsbyn in 1995 have since been replaced by conventional toilets. This was due to technical defects and the lack of a scheme for hazard-free recycling of nutrients to agriculture.

From Urine to Fertilizer. The fertilizer produced in the urine treatment plant at the Birs I WWTP (Urevit) is a nutrient solution that differs substantially from the urine on which it is based (Tab. 2). The liquid fertilizer is characterized by a fourfold higher concentration of nitrogen, phosphorus, potassium and other salts, the absence of micropollutants, bacteria and viruses, and a slightly lower content of organic components.

In Switzerland, as in most European countries, a product licence is required for fertilizers, with various classes being distinguished by the Swiss Fertilizer Marketing Ordinance (DüBV) of 2001 [6]. Mineral nutrient and urea fertilizers are considered to be unproblematic and can be applied without an approval procedure. Approval is, however, required for organic and farmyard fertilizers (e.g. slurry and silage effluents), and fertilizers based on meat-, bone- and bloodmeal are prohibited altogether. For all other fertilizers not explicitly mentioned in the list, an application has to be submitted for licensing based on an approval procedure. This also applies to human urine and urine products. For approval to be

granted, it has to be demonstrated that use of the product is not harmful to humans, animals or the environment, and that there are no adverse impacts on the foodstuffs produced.

Urebit has now received a provisional licence from the Federal Office for Agriculture. At the same time, efforts are being made to secure general approval and fundamental regulations for additional urine-based fertilizer products. The conditions specified cover the following points:

- ▶ Comparison of effectiveness with conventional fertilizers in field trials (including conditions for use in organic farming).
- ▶ Designation and chemical composition of the product.
- ▶ Instructions for application of the product.
- ▶ Proof of hygienic acceptability.
- ▶ Proof of absence of micropollutants (below the detection limit).

The Research Institute of Organic Agriculture (FiBL) in Frick investigated the effectiveness of Urebit as a fertilizer on fodder maize. These studies showed that Urebit is essentially suitable for use as a fertilizer. Whether crops were treated with ammonium nitrate or Urebit, plant growth achieved the maximum level in both cases and was significantly higher than with cattle slurry. However, the total yield was 13% greater with ammonium nitrate than with Urebit. Ammonium is probably lost to the air during the application of Urebit. Such losses could be prevented by alternative spreading methods, and yields could then be expected to equal those obtained with the use of ammonium nitrate.

Making Good Use of the Time Available. The pilot experiments on urine treatment in Basel-Landschaft are initially restricted to a period of six years. Within this time frame, Eawag intends to develop further processes for urine treatment on a laboratory scale. One promising process is phosphate recovery using biological methods or with the aid of magnesium ammonium phosphate



Is Urebit an effective fertilizer? The leaf colour of the plant (in this case fodder maize) is one of the assessment criteria.

(MAP). Urine for these experiments is collected by Eawag at its new headquarters, the Forum Chriesbach building, which – like the Cantonal Library in Liestal – has been fitted exclusively with NoMix toilets.

On the international front, too, research efforts concerning alternative wastewater management and new urine treatment processes are likely to be stepped up in the coming years. This trend is encouraging, for ultimately the more experience is accumulated, the better the prospects for the widespread adoption of the new concepts and technologies. ○ ○ ○

Tab. 2: Composition of untreated urine and Urebit, the liquid fertilizer produced in the urine treatment plant (initial data).

Parameter	Untreated urine	Urebit
pH	8.7	9.1
Conductivity (µS)	–	150
Dissolved organic carbon DOC (g/l)	1.2	3.0–3.5
Chemical oxygen demand COD (g O ₂ /l)	3.6	10
Total nitrogen (g/l)	3.0	12
Ammonium (g/l)	2.9	11
Total phosphorus (g/l)	0.18	0.65
Potassium (g/l)	1.4	5.7
Magnesium (g/l)	–	0.008
Calcium (g/l)	–	0.020
Sodium (g/l)	1.6	6.5
Chloride (g/l)	3.0	15
Sulphate (g/l)	0.7	2.5

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Urine Treatment: from Laboratory to Practice



Wouter Pronk, biotechnology process engineer, head of the Membrane Technology group in the Urban Water Management Department

The combination of electrodialysis and ozonation is a possible method for recovering valuable nutrients from urine in a concentrated form. At the same time, hazardous substances can be removed, yielding a perfectly acceptable fertilizer. The processes developed at Eawag are currently being tested at a pilot plant in Canton Basel-Landschaft.

The high nutrient content of urine makes it an obvious candidate for use in fertilizer production. However, it is necessary to ensure that the pharmaceutical residues and hormones which are also excreted in urine are first separated from the nutrient salts. In order to reduce the transport and storage volume of urine and urine-based fertilizer, the salts should also be recovered in a highly concentrated form.

With these goals in mind, researchers at Eawag studied a series of methods in the laboratory, including complexation, precipitation, ozonation and various membrane processes such as nanofiltration and electrodialysis. For the pilot project to produce fertilizer from urine, a two-stage method was ultimately selected, consisting of electrodialysis and ozonation.

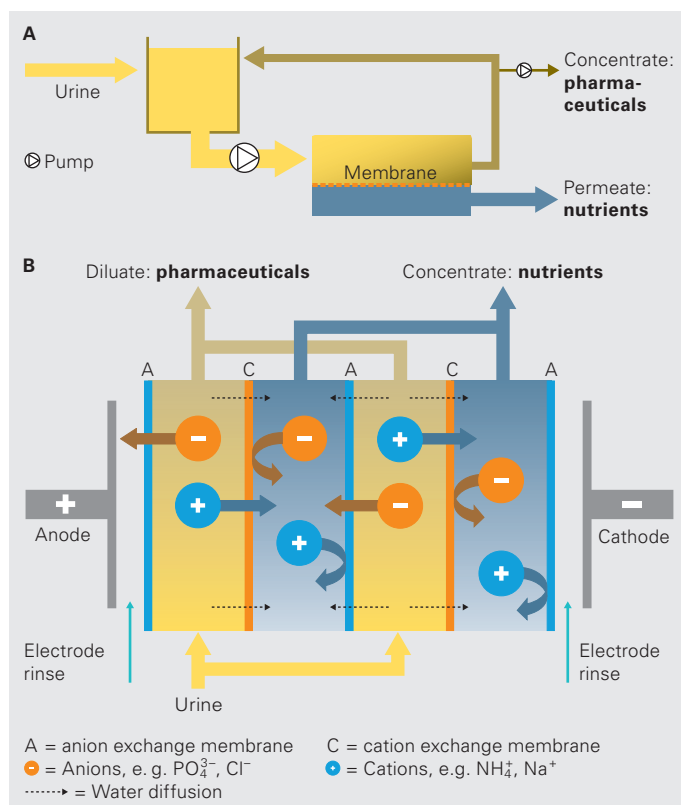
Nanofiltration: Separation of Substances on a Molecular Scale. In the process known as nanofiltration, liquids are forced under high pressure (approx. 10–30 bar) through a membrane with a pore diameter on the order of nanometres (Fig. 1A). In principle, the substances dissolved in the liquid can thus be separated on the basis of molecular size, but their electric charge also plays an important role. We wished to establish whether nanofiltration could also be applied to urine, so that the nutrients contained in this solution – nitrogen and phosphorus – could be separated from the undesirable substances.

In laboratory experiments, we tested three different membranes designed to retain substances with a molecular weight greater than about 150–400 daltons (Da) [1]. Urine was spiked with a representative mixture of pharmaceuticals, including the beta-blocker propranolol, the anti-inflammatory agents diclofenac and ibuprofen, and the active ingredient of oral contraceptives ethinyl estradiol. The molecular weights of these compounds are between 180 and 300 Da, while the molecular weights of the nutrients are much lower. In fresh urine, nitrogen occurs predominantly in the form of urea (60 Da), with ammonium (NH_4^+ , 18 Da) accounting for only a small fraction (approx. 16%); phosphorus occurs exclusively as phosphate (PO_4^{3-} , 95 Da). In stored urine, however, nitrogen mainly occurs in the form of ammonium. This is produced by bacterial hydrolysis, which converts urea to ammo-

nium and carbon dioxide. As a result, the pH of urine also increases during storage, from 6 to 9. In our nanofiltration experiments, fresh, non-hydrolysed urine was used.

Recovery of Urea from Urine by Nanofiltration. In a comparison of various types of membrane, the NF270 membrane (manufactured by Dow Inc.) showed the best performance. But even

Fig. 1: Schematic view of nanofiltration (A) and electrodialysis with two cell pairs (B). In practice, membrane stacks comprising up to 100 cell pairs are used in electrodialysis.





Wouter Pronk, Eawag

Pilot plant for the production of a liquid fertilizer from urine. The urine used comes from the Basel-Landschaft Cantonal Library in Liestal, a new building fitted exclusively with NoMix toilets.

with this membrane not all pollutants were retained (Fig. 2A). In addition, the membrane was not permeable to phosphate, and barely half of the ammonium was able to pass through (Fig. 2B). Satisfactory results were only obtained in the case of urea. Phosphate, for example, is retained as a result of electrostatic repulsion between the membrane and solute. In contrast, the uncharged urea molecules can permeate the membrane. In view of this complex situation, nanofiltration is of limited suitability if nutrients are to be fully recovered.

Electrodialysis: Movement of Substances in an Electric Field.

A more suitable process is electrodialysis (Fig. 1B): arranged alternately between a pair of electrodes (an anode and a cathode) are positively and negatively charged membranes, which in principle permit the passage of charged molecules with a weight of up to

around 200 Da. Positively charged molecules, known as cations, are attracted towards the cathode, while negatively charged molecules, the anions, migrate towards the anode. However, as the cations are unable to pass through the positively charged (anion-exchange) membranes, their concentration increases in the adjacent compartment. The same applies – in the opposite direction – for the anions. Substances are thus removed in the diluate compartments and enriched in the concentrate compartments. Urine is fed into the diluate compartments. Water diffuses from the urine through the membranes into the concentrate compartments, determining the concentrate flow rate.

Almost Complete Separation of Nutrients and Micropollutants by Electrodialysis. With electrodialysis, the aim is that the low-molecular-weight nutrients should migrate into the

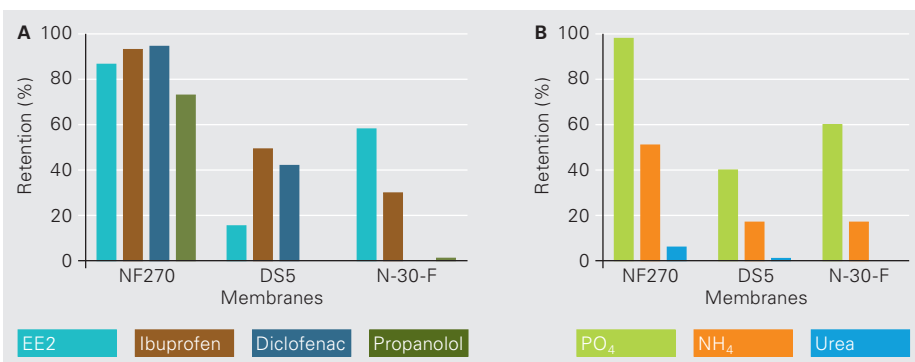


Fig. 2: Retention of pharmaceuticals (A) and nutrients (B) with nanofiltration, using three different types of membrane (EE2 = ethinyl estradiol).

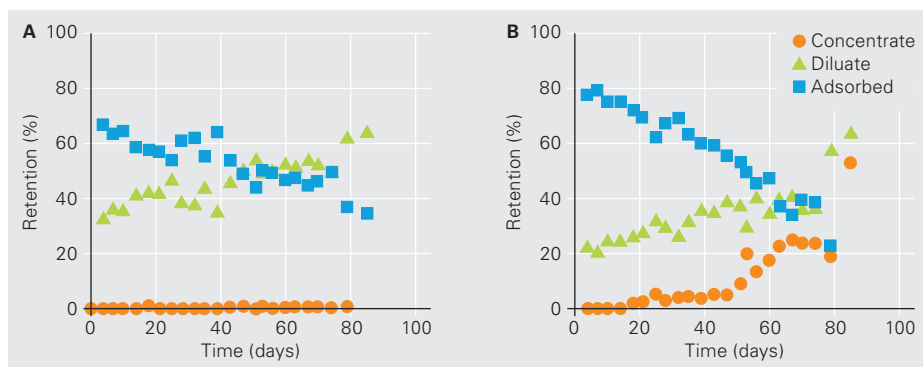


Fig. 3: Mass balances of ethinyl estradiol (A) and propranolol (B) in electro dialysis.

concentrate, while the higher-molecular-weight pharmaceuticals and hormones remain in the diluate. Some of the micropollutants, such as ethinyl estradiol (Fig. 3A) and diclofenac, are effectively retained over an extended period. For propranolol, however, the membrane only represents a barrier at the beginning of electro dialysis, and diffusion occurs with prolonged operating times (Fig. 3B). Among the nutrients, ammonium and phosphate, as expected, are fully transported into the concentrate [2], where they are enriched by a factor of 3–4. With this method, urea cannot be completely recovered: as the molecule does not carry a charge, only a relatively small fraction diffuses into the concentrate. In general, however, the urine to be treated has been stored for some time and no longer contains urea.

Elimination of Remaining Micropollutants by Ozonation.

Since it was not possible to separate all of the unwanted substances from the nutrients by electro dialysis, we tested an additional treatment step. From earlier Eawag experiments involving purified wastewater, it was known that pharmaceuticals can be largely destroyed by oxidation with ozone. Our supplementary laboratory tests indicated that this is also possible in the case of urine or the products of electro dialysis. The dose required – 1–2 g of ozone per litre of urine – is, however, higher than for other applications [3].

Pilot Experiments in Canton Basel-Landschaft.

In a project initiated by the utilities agency of Canton Basel-Landschaft (AIB), NoMix toilets and a urine collection system were installed at the newly built Basel-Landschaft Cantonal Library in Liestal. Together with the AIB, Eawag decided that the urine collected here should be treated in a pilot plant, combining the processes of electro dialysis and ozonation. Initially, we tested two different combinations of these methods: ozonation of untreated urine prior to electro dialysis, and ozonation of the concentrate and diluate following electro dialysis. It was shown that, overall, ozone and energy requirements were lower with subsequent treatment than with prior treatment. Since surface-active substances released when untreated urine is stored may lead to foaming during ozonation, an additional step is required: the untreated urine is prefiltered using a microfiltration membrane. Treatment at the pilot plant thus now

comprises microfiltration, electro dialysis and subsequent ozonation of the two product streams. This combination of urine treatment processes has proved effective: the plant has experienced more than a year of stable operation.

The liquid fertilizer yielded by processing at the pilot plant has been named “Urevit”. Details of the composition of this product, its effectiveness as a fertilizer and the fertilizer approval procedure are to be found in the article by Markus Boller on p. 17.

A Milestone for NoMix Technology. The development of a feasible method for the production of a urine-based fertilizer is a milestone in the implementation of the NoMix concept. Among the public, the motivation to install and continue using urine-diverting toilets has been shown to be increased if realistic options for recycling urine can be demonstrated. Although definitive regulatory approval for the liquid fertilizer produced using our method is still outstanding, we are highly confident that it will be granted.

The pilot project at the Cantonal Library in Liestal, including the urine treatment plant, is supported by the ETH Domain Novatlantis sustainability programme. ○ ○ ○

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Can NoMix Help to Prevent Environmental Problems Caused by Medicines?



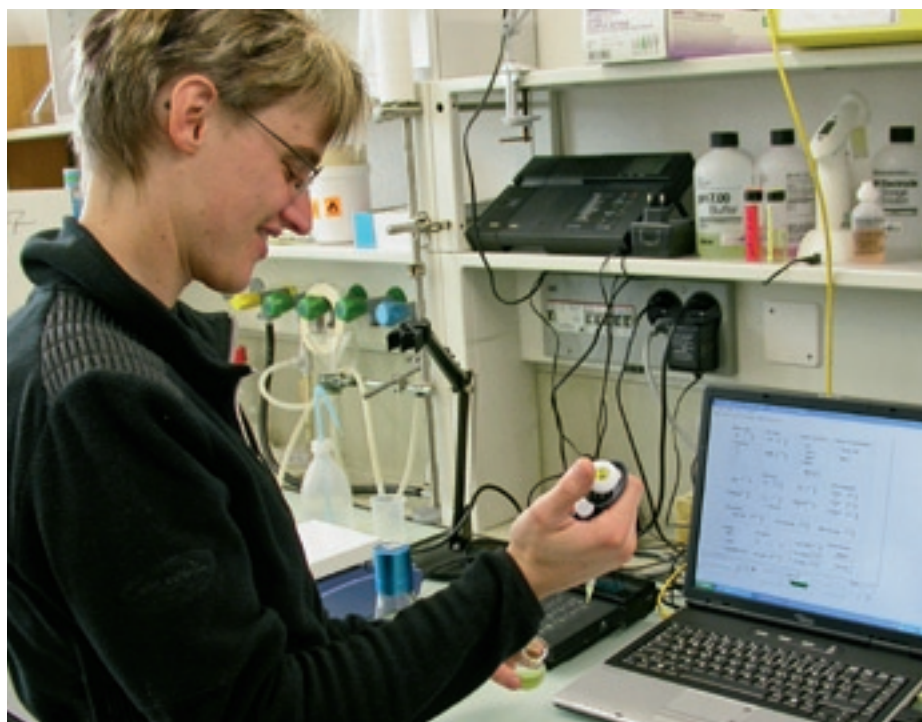
Beate Escher, chemist and head of the "Mode-of-action based Ecotoxicological Risk Assessment" research group
Co-author: J. Lienert

One of the aims of the NoMix system is to produce fertilizers from source-separated urine. But urine also contains traces of pharmaceuticals and hormones, which need to be completely removed during treatment. To assess the efficiency of treatment processes, we developed a procedure combining chemical and ecotoxicological analytical methods.

Many of the medicines that we consume are excreted in urine. This is also true of hormone products, such as oral contraceptives, and even hormones produced naturally within the body. These substances enter wastewater streams and are conveyed to treatment plants, where in many cases they are not completely eliminated. They can therefore subsequently be detected in receiving waters, albeit generally in very low concentrations – in the nanograms to micrograms per litre range. Together with other organic compounds found in the environment, pharmaceutical

residues are known as micropollutants. Individually, these substances rarely pose a risk to aquatic life, but as mixtures, they may well have adverse impacts. Collection of urine at source, i.e. in NoMix toilets, followed by separate treatment thus represents a significant opportunity. But here too, there is a need to ensure that micropollutants are not released into the environment – especially if a fertilizer is to be produced from the urine. Accordingly, as part of the Novaquatis project, we developed a testing procedure which both allows individual substances to be chemically detected and enables mixtures of pollutants to be analysed for ecotoxicological effects. This makes it possible to monitor the fate of micropollutants throughout the urine treatment process.

The algal assay is used to determine non-specific toxic effects of pharmaceuticals.



Yvonne Lehnhard, Eawag

Ecotoxicological Analysis: Yeast Screen for Hormonal Activity and Algal Assay for Cytotoxicity.

The fact that urine is a complex mixture of substances makes ecotoxicological assessment difficult. In order to be certain that the effects observed were not caused by the pH value of urine, or by salts or other natural components, we first had to isolate the micropollutants from the urine. For this purpose, we successfully refined an existing method of solid-phase extraction [1]. The extracts thus obtained were subsequently subjected to a series of ecotoxicological tests designed to detect various modes of action *in vitro*. This approach can be used, for example, to find out whether a urine sample damages cell membranes, disrupts photosynthesis or is toxic to genetic material. The tests were originally

developed to assess the hazards posed by pharmaceuticals to aquatic organisms [2].

As we aimed to analyse a large number of urine samples rapidly and economically in the Novaquatis project, we focused on two bioassays of particular relevance [1, 3]. The yeast estrogen screen (YES test) indicates whether hormonally active micropollutants, such as the sex hormones estradiol and ethinyl estradiol (active substance of oral contraceptives), are present in urine [4]. The algal assay is used to detect substances with non-specific toxic effects on cells by determining the extent to which algal photosynthesis is inhibited.

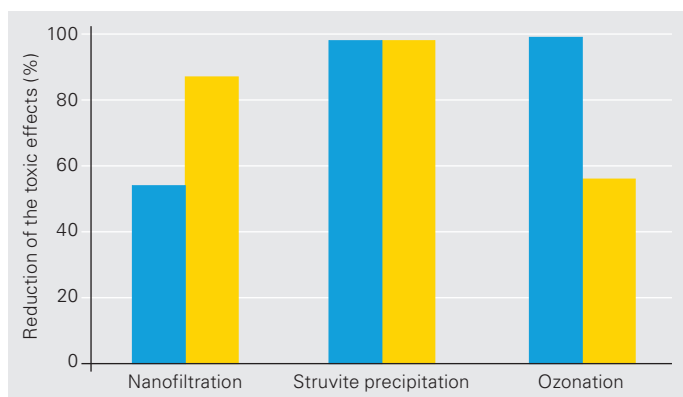
In both cases, it is not specific agents that are detected but the effects caused by the mixture of substances contained in the urine. For each of these parameters, the potency is first determined in untreated urine and this value is set at 100%. Decreases in estrogenic activity and in cytotoxicity can then be monitored in the course of urine treatment.

Greater Elimination of Pollutants with Struvite Precipitation than with Nanofiltration and Ozonation. As part of the Novaquatis project, a variety of processes were developed for the treatment of urine (see the article by Max Maurer on p. 14). Here, however, we focus on only three methods: nanofiltration and struvite precipitation for fertilizer production, and ozonation for the removal of micropollutants (the overall results of the study are presented in [3]).

When nanofiltration is used to produce a fertilizer (see the article by Wouter Pronk on p. 20), the nutrients are to be found in the liquid that passes through the filter, i. e. in the so-called permeate. The bulk of the pharmaceuticals and hormones accumulate in the solution that is retained (and disposed of), with estrogen activity being reduced by 54% and cytotoxicity by 87% in the permeate (Fig. 1). Struvite precipitation is even more efficient, removing 98% of the hormonally active and cytotoxic micropollutants, and thus leaving a clean fertilizer product (Fig. 1).

In the ozonation process, very high doses of ozone are used to eliminate micropollutants. This is due to the fact that, apart

Fig. 1: Decreases in estrogenic activity (blue) and cytotoxicity (yellow) observed with three different methods of urine treatment. The reduction is expressed as a percentage of the pre-treatment value.



from pharmaceuticals and hormones, urine naturally contains large quantities of organic substances. With the ozone dose applied in our method (1.1 g per litre of urine), the organic compounds are oxidized to such an extent that estrogenic activity is completely eliminated. However, this dose is not sufficient for the cytotoxic substances to be also completely destroyed. In our tests, cytotoxicity was only reduced by a little more than 50% (Fig. 1). Consequently, the urine must still contain relatively large molecular fragments.

Chemical Analysis: Measurement of Specific Substances.

With the aid of chemical analysis, we also investigated whether certain commonly used pharmaceutical agents that are partially excreted in urine – such as propranolol, ibuprofen, diclofenac, carbamazepine and ethinyl estradiol – remain detectable after urine treatment. In our tests, to facilitate detection, urine was spiked with a known quantity of each of these agents prior to treatment. By and large, the results of the ecotoxicological tests were confirmed by the chemical analysis [3].

Chemical and Ecotoxicological Tests: Mutually Complementary.

Depending on the specific question, either chemical or ecotoxicological analysis or a combination of these methods can be used. For example, if the behaviour of individual substances is to be characterized, chemical analysis is appropriate. The ecotoxicological tests are more suitable for estimating how efficiently an unknown mixture of micropollutants is removed by a given treatment process. In these tests, the combined effects of all the components in the mixture are measured – including unknown substances and metabolites, and pharmaceuticals present in the urine in extremely small amounts. However, certain natural urine components also contribute to the overall toxicity.

Urine Source Separation to Reduce Pollutant Loads in Waterbodies?

Our results show that, with appropriate treatment, it is possible to obtain a pollutant-free urine-based fertilizer product. But our research involves the pursuit of further questions: Could micropollutant loads in wastewater streams be significantly reduced by consistent application of urine source separation? And would this make it possible to relieve the burden on wastewater treatment plants and to avoid environmental problems?

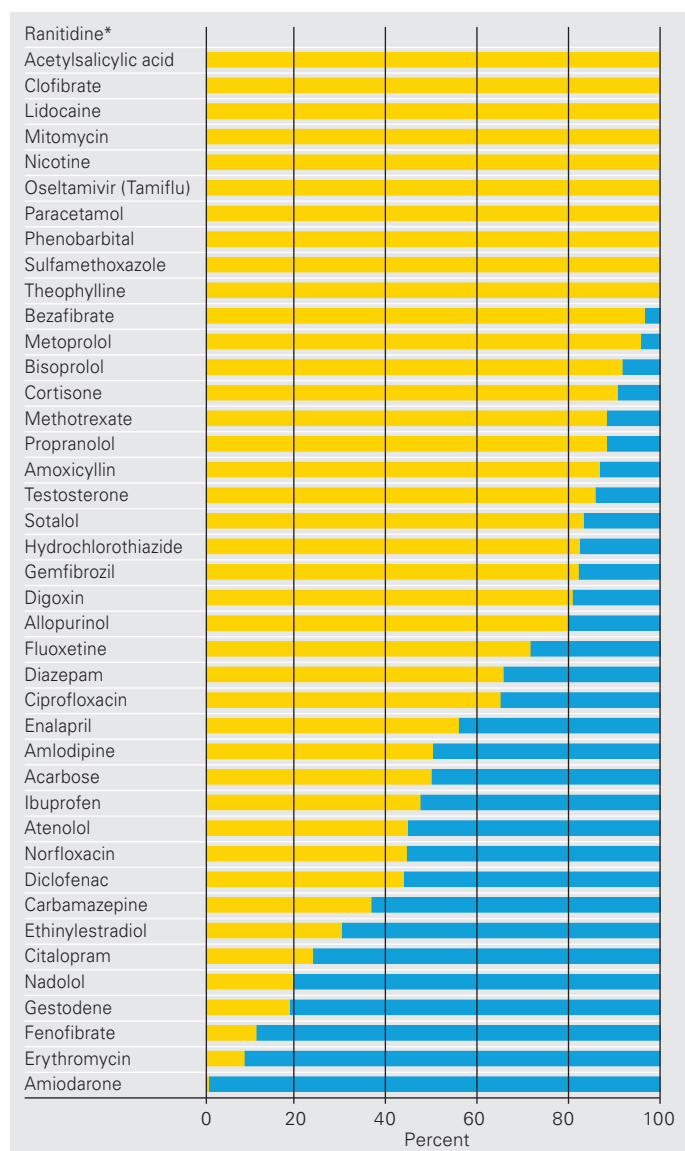
To assess these questions, one needs to know how medicines and hormones behave in the body. In general, a certain proportion of the active ingredient is absorbed, transformed (metabolized) and – given the generally higher water solubility of the metabolite – often excreted in the urine. The remainder, which is not absorbed or is less heavily metabolized, leaves the body with the feces. We therefore estimated the relative proportions excreted via the urinary or fecal route for 212 pharmaceutical substances [5]. Although the variation among individual medicines is extremely wide, an average of 64% (standard deviation $\pm 27\%$) of a substance ingested is excreted in the urine.

Another factor that needs to be taken into account is the toxicity of individual metabolites to aquatic organisms. Here, we used modelling techniques to estimate the toxicity of the urinary and

fecal fractions for 42 pharmaceuticals widely used in Switzerland [6, 7]. The model is based on the assumption that the biological activity of a substance depends on its chemical structure. As a general rule, the more hydrophobic or poorly water-soluble a substance, the greater its toxicity to aquatic organisms. This would suggest that the toxicity of the fecal fraction is generally

Fig. 2: Mean relative toxicity of the urinary (yellow) and fecal (blue) fractions for 42 pharmaceutical active substances after metabolism in the human body [7]. The values are scaled up to 100%. It is not possible for the various substances to be compared in absolute terms. For example, the entire toxicity of acetylsalicylic acid resides in the urine, whereas in the case of diclofenac only 44% of the toxicity is excreted in the urine. Nonetheless, it is possible that the residues of diclofenac excreted via this route pose a greater risk to aquatic organisms than those of acetylsalicylic acid. To investigate this, further modelling is required [7].

* No suitable literature data on ranitidine available for this specific modelling procedure.



higher than that of the urinary fraction. However, the situation is more complicated, since not only the chemical properties of the metabolites but also the quantity needs to be considered, and the greater part of an active substance is usually excreted via the urinary route. Our analysis, indeed, revealed major variations (Fig. 2). Nonetheless, for 24% of the substances studied, toxicity is released exclusively via the urine, and for 67% at least 50% of the total toxicity is excreted in the urine [7]. With urine source separation, it is thus possible to prevent a large proportion of pharmaceuticals and hormones from entering wastewater. This would not only relieve the burden on wastewater treatment plants but also reduce water pollution. ○ ○ ○

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Applying Traditional Chinese Knowledge



Tove A. Larsen, chemical engineer and project leader of Novaquatis
 Co-authors: H.-P. Bader, H.-J. Mosler, W. Gujer, E. Medilanski, R. Scheidegger, D.-B. Huang, R. Schertenleib

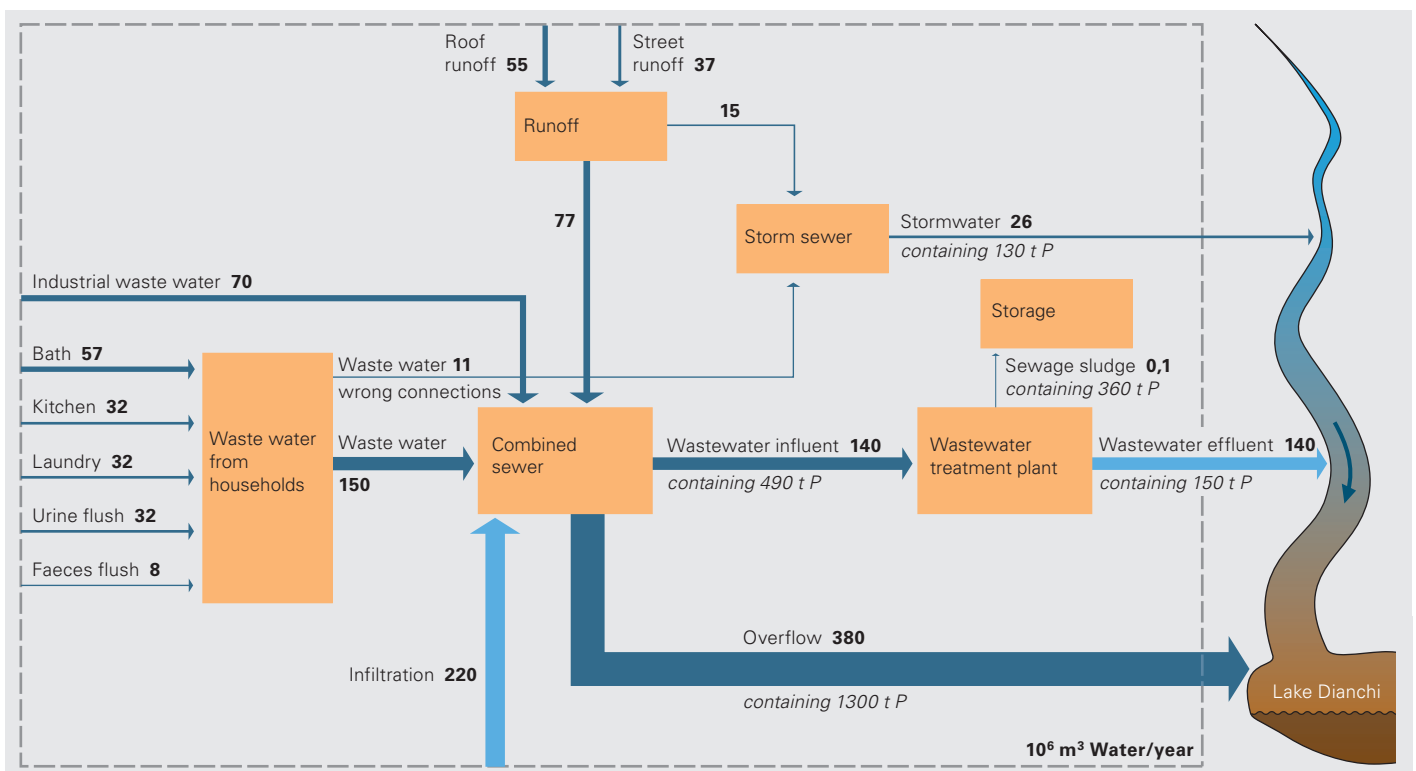
Kunming, Zurich's sister city in China, is determined to tackle its wastewater problem. In the development of measures based on nutrient recycling – a long-established principle in China – it is receiving support from Eawag in technical as well as social issues.

Drinking water supplies for Kunming's population of several million are largely drawn from Lake Dianchi. However, this shallow lake is heavily contaminated with phosphorus as a result of wastewater discharges from the city and regional agriculture. For some time now, the abstraction of drinking water from the lake has been steadily reduced, and withdrawals will probably be stopped altogether in the near future. In view of this precarious situation, the authorities have called for efforts to restore the quality of lake water to the 1960 standard. However, the question remaining is how this objective can be achieved, given the complexity of the

system and the fact that possible measures need to be effective both technically and socially.

Can Source Control Measures Solve the Problem? Measures taken at source represent important alternatives to conventional treatment technologies. China has a long tradition of nutrient recycling, and in rural areas urine has long been used as a fertilizer. Does this mean that urine separation would be a possible option for improving water quality in Lake Dianchi? To investigate this question, a three-part project financed through the Swiss

Fig. 1: Wastewater flows in Kunming in 2000, expressed in 10^6 m^3 per year. The scant local data were supplemented by literature data and reference data from the city of Zurich.



research programme NCCR North-South [1] was carried out by Eawag in Kunming. It involved:

- ▶ analysing wastewater flows in Kunming and simulating the outcome of possible measures;
- ▶ surveying the relevant stakeholders on the acceptance of source control measures, the introduction of urine separation, and possible decision-making paths; and
- ▶ launching a pilot project to test urine-diverting waterless toilets in a rural area.

Kunming's Urban Drainage System. Using a simple material-flow model developed for the drainage system in Kunming, we sought to establish the quantities of nutrients deriving from various sources [2]. In the model, water, nitrogen and phosphorus flows are represented, together with the main sources of wastewater:

- ▶ households (broken down into five categories: bath, kitchen, laundry, urine flush and faeces flush),
- ▶ industry,
- ▶ street and roof run-off,
- ▶ sewer infiltration (including groundwater and river water).

Wastewater flows and phosphorus loads are shown in Figure 1. It became evident that the capacity of the sewerage system and of wastewater treatment plants (WWTP) is inadequate, and that WWTP technology is not sufficiently advanced. Only about 25% of the collected wastewater is treated at one of the six WWTPs, with most of the remainder entering the lake untreated via overflows. The problem is exacerbated by unwanted infiltration water, which dilutes wastewater in a ratio of at least 1:1. As a result, around 1600 of a total of 1960 tonnes of phosphorus from the city flow into Lake Dianchi each year. According to an estimation [3], however, annual inflows of phosphorus into the lake should not exceed 60 tonnes if the water quality of 1960 is to be restored. Allowing for the current ratio of urban/agricultural inputs – approximately 1:1 [4] – the target level would thus be less than 30 tonnes of phosphorus discharged from the city per year. These conclusions are essentially unchanged even if the high level of data uncertainty is taken into account.

Specific Remedial Measures. In order to develop proposals for appropriate remedial measures, various scenarios were simulated using the material-flow model [2]. Of these scenarios, the two most important were:

- ▶ BAT (best available technology) – upgrading of Kunming's urban drainage system to up-to-date standards, as complied with, for example, in Zurich: reduction of infiltration, elimination of misconnections, increase in sewerage system capacity and application of best available treatment processes in WWTPs. The required alterations to the sewer system would make this option extremely costly and exceedingly difficult to implement.
- ▶ BAT plus urine separation, with two thirds of all households being equipped with urine-diverting toilets.

Under both scenarios, the phosphorus load is substantially reduced. Nevertheless, with the BAT option, 56 tonnes of phosphorus per year would still be discharged from the city into Lake



Fig. 2: Two urine-separating sanitary systems: waterless toilet (left) and NoMix flush toilet (right).

Dianchi. The end-of-pipe approach would thus, in itself, not be sufficient to attain the desired level of water quality. This measure could be supported by diverting part of the treated wastewater into other receiving waters. However, this would produce adverse ecological impacts, as Lake Dianchi would no longer receive sufficient water. Consequently, there is no simple solution; instead, a combination of measures is required. According to the simulation, the amount of phosphorus discharged into the lake under the “BAT plus urine separation” scenario is only 39 tonnes per year. As we consider the BAT option to be somewhat unrealistic, there is a need for additional source control measures – urine separation alone is not enough. Whatever options are chosen, successful implementation depends crucially on a careful assessment of feasibility, with the involvement of all stakeholders.

Stakeholders' Attitudes to Urine Separation. Before new technologies can be introduced on a large scale, it is essential to determine the relevant actors' interests and readiness for action, and to be aware of the relevant decision-making processes. Accordingly, we conducted an in-depth stakeholder analysis [5, 6]. Thirty-five different stakeholders from political, administrative, scientific and business circles were identified and characterized in terms of their interest in urine-diverting toilets and their impact with regard to the introduction of this type of sanitary system. The greatest influence on this process is wielded by the key stakeholders – namely, the Congress, the government, the Communist Party, the Lake Dianchi Protection Authority, and the municipal and national environmental protection agencies, but also real estate companies and the urban planning authority.

The vast majority of stakeholders consider source control measures, especially in the area of industrial and sanitary wastewater, to be necessary and also feasible in the next 20 years. Overall, positive ratings were given to the technical feasibility and environmental effects of urine separation, and also to social acceptance and institutional flexibility in relation to the introduction of this technology. Asked about which of the two urine-diverting systems the stakeholders would prefer (Fig. 2), they favoured the NoMix flush system over the less costly waterless toilet (Fig. 3). It was, however, pointed out that NoMix systems could certainly be produced more cheaply in China than in Western countries.

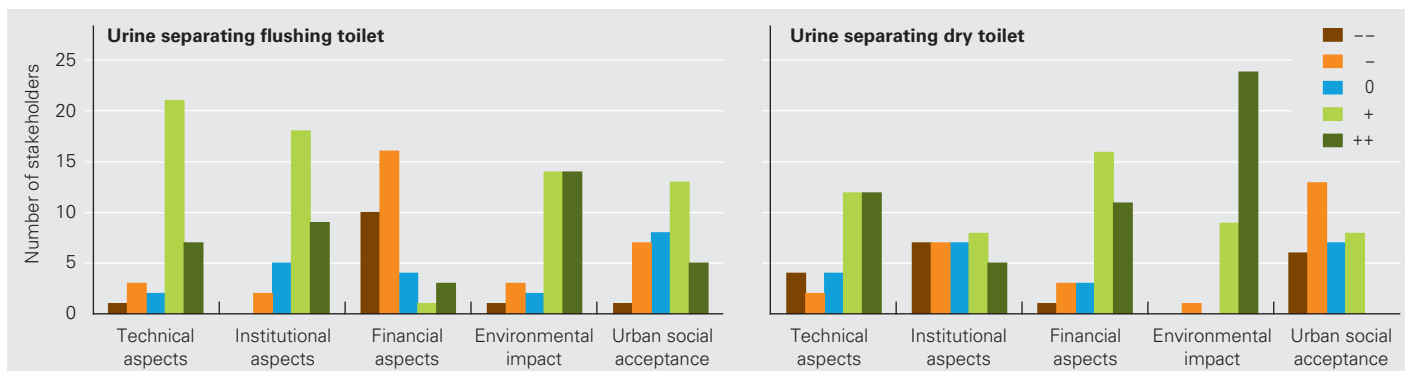


Fig. 3: Stakeholders' views on two different urine-diverting toilet systems. Assessments on a scale from highly negative (--) to highly positive (+).

Importance of a Smooth Decision-making Process. The stakeholder analysis was also designed to identify the decision-making processes involved in the implementation of urine separation. What form would these take in practice, if urine-diverting toilets were to be widely introduced in Kunming City? A measure of this kind would require a submission to central government and the National People's Congress prepared by the national environmental protection agency in cooperation with the Lake Dianchi Protection Authority. If the submission were approved in principle, the Kunming Institute of Environmental Science would initially be charged with conducting a pilot project to study feasibility on a small scale. Only after successful completion of the pilot project could urine separation be introduced on a large scale by the Lake Dianchi Protection Authority.

One striking finding is the existing institutional flexibility: although the law provides for central wastewater treatment, it is also perfectly possible – under the current five-year plan – to carry out innovative pilot projects in the city.

Pilot Project: Urine-diverting Toilets in a Rural District. In cooperation with Eawag, the Kunming Institute of Environmental Science launched a pilot project involving the installation of over 100 urine-diverting waterless toilets in a rural district on the outskirts of Kunming [7]. While experiences are positive, the results also indicate the objections and problems likely to be encountered in the event of widespread introduction. According to a quantitative study of satisfaction with the technology [8], the waterless toilets are presently only used by about 40% of the residents; the users are, however, largely satisfied. The main problem cited is the question of location: a preference has been expressed for installing the toilets outdoors, if possible even outside the users' own plot. No doubt, this is partly attributable to concerns about odour problems.

Persistence and Courage to Pursue a Sustainable Solution.

Overall, it turns out that urine separation can make a significant contribution to solving Kunming's wastewater problems, although different approaches will probably be required for rural and urban areas. It is also obvious that Kunming City is making strong efforts

to restore the quality of the lake which has been deteriorating due to intense population pressure. For this extremely challenging task there is no standard solution – neither the modernization of Kunming's sewerage system combined with a diversion of the treated wastewater nor urine separation alone can solve the problems of Lake Dianchi. A combination of measures will be needed, as will persistence and the courage to experiment, so that appropriate solutions can be developed and tested before they are implemented on a large scale. ○ ○ ○

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Conclusions

Urine Recycling: First Practical Experience

In 2002, the Construction and Environmental Protection Department (BUD) of Canton Basel-Landschaft initiated a pilot project on the recycling of source-separated urine. The main goals were to study the feasibility of alternative wastewater management systems, to close nutrient cycles and to remove problematic substances from the hydrological cycle.

Since June 2005, urine collected at the Cantonal Library in Liestal has been used to produce 20–30 litres of a pollutant-free liquid fertilizer ("Urevit") per week. A provisional fertilizer licence has been granted by the Federal Office for Agriculture.

What we have learned to date:

► *Collection:* The NoMix toilets show deficiencies in the areas of hygiene, usability and maintenance. Here, further development is required. Water-free urinals are well established. In view of odour emissions, the location of the urine storage tank needs to be carefully planned.

► *Treatment:* To protect electrodialysis membranes, a prior ultrafiltration step is carried out. The nutrient concentration is increased fourfold. No trace substances are detectable.

► *Recycling:* Urevit is a high-quality agricultural fertilizer. The release of ammonia gas calls for a more elaborate spreading technique than is required for artificial fertilizers. In the cultivation of ornamentals, volatilization and high salt concentrations need to be taken into account.

With urine source separation, the defined goals can be achieved. However, as the plant is still under development, the production costs for Urevit are currently higher than for artificial fertilizers. Nevertheless, we intend to pursue this option, focusing however on institutions where special wastewater (hospitals) or large volumes of urine (stadiums) arise. ○ ○ ○



Toni von Arx, head of the utilities agency (AIB), Canton Basel-Landschaft

Cleaning up Oceans with NoMix

Since 2004, according to the United Nations Environment Programme (UNEP), the number of "dead zones" in coastal waters has risen from 150 to more than 200. With the total doubling every 10 years, they are already endangering the development of fish stocks to the same extent as overfishing. Oxygen-depleted dead zones develop as a result of the eutrophication of marine waters with nitrogen and phosphorus – certainly one of the major water pollution control issues of the future.

In the industrialized world, it took us around 100 years to build up a waterborne sewage system – creating many water pollution problems in the process. The development of effective wastewater treatment plants took over 50 years, and this work is far from complete, as nutrient inputs to marine waters are still too high.

Transferred to the world's fast-growing urban populations, our existing sanitation system would vastly increase marine eutrophication. Any subsequent remediation efforts would be costly, prolonged and probably too late. Novaquatis offers an alternative. The NoMix system not only makes it possible to recover and recycle nutrients, but also helps to save precious water and realize additional benefits.

The technologies in question can only be exported if we in industrialized countries demonstrate that source control measures satisfy the most exacting hygienic and aesthetic requirements. As well as relieving the pressure on the seas and our own waters, this provides an opportunity for us to develop an attractive export product in cooperation with Swiss industry. So, in the first instance, it is up to us to devise and consistently use new systems. This is the only way of ensuring that adequate supplies of fish remain available for human consumption worldwide. ○ ○ ○



Willi Gujer, Member of the Eawag Directorate, Professor of Urban Water Management at the ETH Zurich

Now it's up to the Practitioners

Novaquatis impressively demonstrates that wastewater disposal could be quite different from what we are used to. The project calls traditional ideas into question and stimulates reflection on how the wastewater management world could look. This in itself marks a major achievement.

One of the main challenges for urine source separation is the question of how and where the nutrients excreted in urine are to be converted into fertilizers. At first glance, new pipes for conveying urine, or transport in tankers, do not appear to be particularly attractive options. But that could change, for example, if urine removal were combined with refuse collection. Equally appealing is the idea that processing could be carried out in a decentralized way.

It is important that the promising solutions developed by Novaquatis should be adopted in practice. The authorities need to approve construction projects using these new technologies even though, naturally enough, no provision is (yet) made for them in existing legislation. And the industry must increasingly participate in the development and production of the new technologies.

Wastewater management, fortunately, is not a theoretical construct, the province solely of scientists and researchers. On the contrary, it is an issue that concerns all of us. The public's appetite for innovations was obvious to me from the long queues that formed on the open day at the "zero-discharge house" in Zuchwil. So the conditions for changes in the wastewater management sector look favourable. Foundations and initial experience are now available. Let's now explore the opportunities and limits of urine source separation. ○ ○ ○



Martin Würsten, Head of the Water Division, Solothurn Environment Office, Chairman, Swiss Water Pollution Control Association (VSA)

Novaquatis Publications

Incomplete literature list; see also www.novaquatis.eawag.ch. Further publications will appear by the end of 2007.

Most of these publications as well as the Novaquatis final report (in English and German) may be ordered from novaquatis@eawag.ch.

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Letter from the New Eawag Director



Janet G. Hering, Ph.D.
Director, Eawag
Professor of Environmental
Biogeochemistry, ETHZ

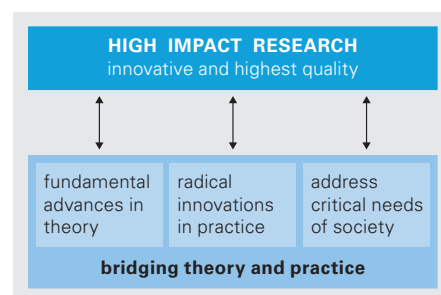
Dear Colleagues and Friends of Eawag,

I am delighted to have this opportunity to address you early in my tenure as Director of Eawag. I am deeply honored to have been selected for this position – it is a tremendous opportunity for me professionally but also a huge responsibility. I am confident, however, that, with the help of Eawag's very talented and dedicated researchers and support staff, I can fulfill this responsibility successfully.

Nearly twenty years ago, I had the great privilege of coming to Eawag to work with Professor Werner Stumm, who was then the director. Under Werner's leadership, Eawag established its worldwide reputation as a leading institute for environmental science and technology. A strong emphasis on fundamental science was a hallmark of environmental research at Eawag. Under the next director, Professor Sascha Zehnder, Eawag's tradition of research excellence was continued. The focus of research was sharpened to emphasize aquatic science and technology but also broadened to include the social sciences and to expand international activities, particularly in developing countries. Most recently, Eawag has benefited from the leadership of Director Ueli Bundi. He has contributed to the definition of Eawag's research activities by emphasizing the action fields, which are highly visible both within and outside Eawag. Another highlight of his tenure was the construction and opening of the Forum Chriesbach, which provides an outstanding example of green architecture.

Now, it is my great challenge and opportunity to follow these outstanding leaders and their predecessors as director of Eawag. With the help of its very talented staff, I look forward to positioning Eawag as the world's foremost institute of aquatic science and technology for the 21st century. Increasing population growth and climate change will result in increasing stresses on water supply and aquatic ecosystems. Rapid development in India and China has already led to significant environmental degradation. Eawag has a critical role to play in developing engineering solutions to these problems and in building the fundamental science base for those engineering solutions. Within Switzerland, communities face the need to replace infrastructure for water treatment and supply and wastewater conveyance and treatment. This is an opportunity for new technologies and new paradigms for water and wastewater management to be implemented. There are also continuing concerns with the viability of fisheries, river restoration, flood protection, and groundwater quality. In all these areas, the possible effects of climate change will need to be addressed.

Eawag is uniquely suited to meet these challenges because it has four great strengths, the combination of which is unique in the world. First, it has a clearly defined focus on aquatic science and technology. Second, it has an outstanding human infrastructure, that is, a staff that includes talented and highly skilled scientists and engineers, highly trained technicians, and dedicated support personnel. Third, it possesses world-class facilities and analytical instrumentation. And, finally, it benefits greatly from the strong support it receives from the Swiss government and people. This support is crucial because it allows Eawag to forge new directions and to focus on innovative fundamental research and the introduction



Research principles for Eawag.

of novel (even radical) concepts in applied research. It also allows Eawag to fulfill its special role in bridging between theory and practice and engaging stakeholders in the design and implementation of applied projects.

In the coming weeks and months, I hope to engage Eawag scientists and engineers in a far-reaching discussion of the most important future challenges to human society related to the water environment and of the potential role of Eawag in meeting these challenges. I would like to establish for Eawag the goal of focusing on high impact research, that is, basic research that seeks to make fundamental advances in theory, and applied research that introduces radical innovations and addresses the critical needs of society (see Figure). I am pleased that this letter appears in an issue of Eawag News that focuses on an outstanding example of Eawag's applied research, the NoMix technology.

With best wishes for the future success of Eawag,

In Brief

Ambitious Energy Goals

Eawag is further strengthening its commitment to environmentally sound operations: the organization's electricity and heating requirements are to be succes-

sively met by renewables and in an environmentally friendly manner. As well as increasing on-site power generation through photovoltaic systems, Eawag will be switching to certified green power supplies by 2010 – the "naturemade star" label, which was jointly developed by Eawag in the cross-cutting "Ökostrom" project. In addition, with immediate effect, all work-related travel undertaken by Eawag staff is to be carbon-neutral. This will be achieved, for example, by offsetting emissions. ○ ○ ○

Manu Heim, Swiss Solar Agency



Award-winning Forum Chriesbach

Alongside the Swiss Solar Prize and the Swisspor Innovation Prize, the new Eawag headquarter building has now won another two awards. On 8 January, the architect Bob Gysin and Ueli Bundi (representing Eawag) received the 2007 "Watt d'or" – an award granted by the Federal Office of Energy in recognition of outstanding performance and groundbreaking innovations in the energy sector.

At the end of January, the architects Bob Gysin + Partner were the recipients

of the 2007 Daylight Award, which carries a prize of CHF 100 000. The award, sponsored by the non-profit Velux Stiftung, is designed to promote the innovative and sustainable use of daylight in buildings. The Forum Chriesbach project was specially commended for the combination of daylight utilization with the provision of energy for the building. Three quarters of the prize money is earmarked for further promotion of the use of daylight.

www.forumchriesbach.eawag.ch ○ ○ ○

IWMF: New Eawag Workshop

The International Water Management Forum (IWMF) is a new type of event organized by Eawag for decision makers right across the water management sector. As well as promoting the networking of experts and knowledge transfer, the focus is on developing a basis for strategic planning and risk management. Influences

and decision points will be identified and options for action evaluated. The IWMF was held as a pilot event in 2006 focusing on micropollutants. This year's forum, to be held on 4–6 September, is entitled "River Restoration: Decision Making Process and Success Evaluation".

www.iwmf.eawag.ch ○ ○ ○

Assessing rivers and streams

Eva Schager, Eawag



On 25 January, 160 water specialists met in Bern for an update on the Modular Stepwise Procedure for watercourse assessment. The meeting was jointly organized by the Federal Office for the Environment (FOEN), Eawag and the Conference of Cantonal Environmental Protection Directors (KVU). Under the Modular Stepwise Procedure, standardized methods have been developed in the fields of hydromorphology, biology, chemistry and ecotoxicology to permit integrated watercourse assessment. The gathering also provided an opportunity for the sharing of experiences. The project is due to be completed by the end of 2008. In the final stages, the priority concerns – in addition to further development of the modules – are to ensure consistent application of the methods and to coordinate data management at the national level.

Events

PEAK courses

12/13 March

Eawag Dübendorf

The Integrated River Rehabilitation Model (IFRM) – a new tool for watercourse rehabilitation practice (in German)

14–16 March

Eawag Dübendorf

Ecotoxicology course Module R: risk assessment (in German)

28–30 March

Fish in Swiss waters (in German)

25–27 April

Cemagref Lyon

Ecotoxicology course Module E: evaluation of pollutants (in French)

18–21 September

Household centred concepts and technologies for water and environmental sanitation in developing countries

23/24 October

Eawag Dübendorf

The influence of roof and facade materials and design on water quality (in German)

Conference

16 March

Eawag Dübendorf

Development of a European research area: promoting collaboration with the European Commission's Joint Research Centre and Switzerland

Friday Seminars

23 March to 29 June, on Fridays at 11:00

Eawag Dübendorf

Linking science and water management

Details: www.eawag.ch/veranstaltungen

www.modul-stufen-konzept.ch ○ ○ ○