NOVAQUATIS
An integrated research project

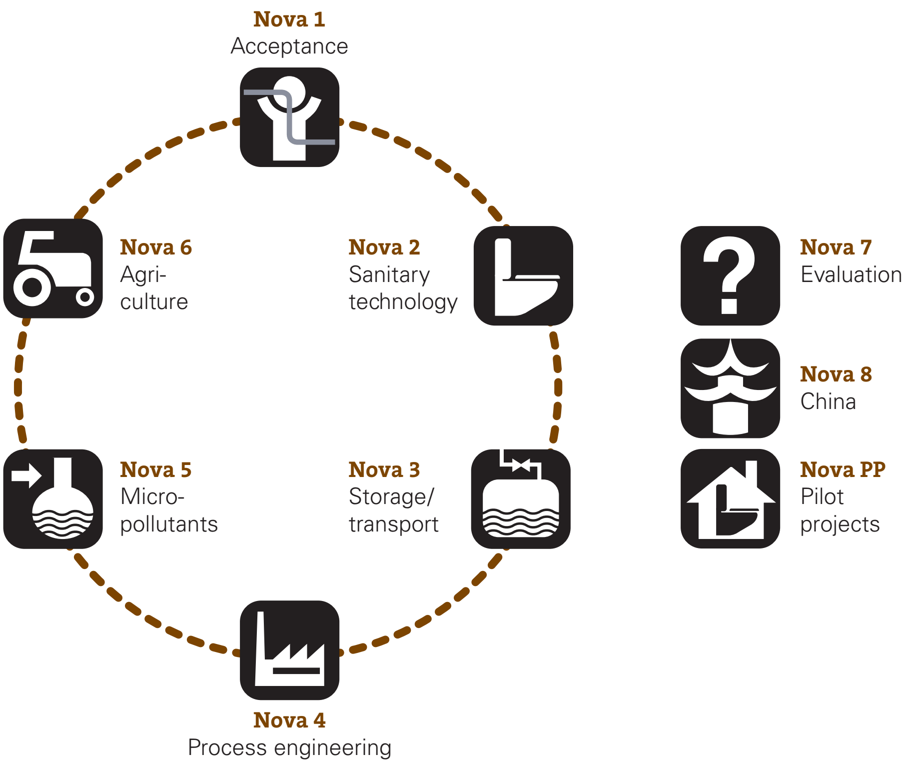
eawag
aquatic research

NoMix

A New Approach to Urban Water Management

Final Report Novaquatis

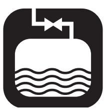
Content



Introduction. The NoMix technology promotes water pollution control and conserves resources. Public attitudes to this innovation are favourable. Various methods have been developed for treating urine and removing micropollutants. Urine transport remains problematic. The results of the Novaquatis project suggest that it would be worth finding solutions to this problem – or avoiding it altogether by treating urine directly on site. For urine source separation could make a significant contribution to resolving the world's increasingly serious water pollution control issues. **4**

Nova 1: Is the NoMix toilet acceptable? An innovation for private bathrooms can only be widely implemented if it is accepted by the public. For this reason, all Swiss NoMix pilot projects were accompanied by sociological studies. 1750 people were surveyed – and their attitudes towards urine source separation are highly favourable. Despite a number of deficiencies, the NoMix toilet is well accepted, especially in public buildings. Further development efforts are now required on the part of the sanitary industry. Currently available models can, however, also be used – with careful supporting measures – in order to contribute to further improvements in urine source separation. **6**

Nova 2: Does the sanitary technology work? The principle of NoMix is simple: urine is collected separately from other wastewater. But, in practice, this is still not as simple as it sounds – especially when it comes to sanitary technology. For example, pipes may be blocked by urine scale, and designing and producing a modern NoMix appliance is a costly enterprise. Novaquatis approached these problems in various ways: through research on precipitation, feedback from pilot projects and round-table discussions to explore the interests of the parties concerned. **8**



Nova 3: Storage and transport. *The* key problem for the NoMix system is how urine is to be transported from the toilet to a central treatment plant. Nova 3 proposes transitional solutions that would allow the NoMix technology to be integrated into the existing wastewater management system and further developed: after temporary storage, urine is transported via the sewer system. Implementation of the NoMix technology in practice is supported by a newly developed computer model. One important finding is that only 60–75 % of urine excreted is collected by today's NoMix toilets. **10**

Nova 4: Urine treatment and fertilizer production. Urine contains high levels of nutrients – and these should not be allowed to enter waterbodies. One attractive option, therefore, could be to recover nutrients for use as fertilizers in agriculture. Novaquatis studied a broad range of processes – biological, chemical and physical – both for the production of fertilizers and for the removal of nutrients. It was shown that the various processes are suitable for different purposes and, in most cases, are not energy-intensive. This means that treatment can be adapted to meet specific requirements. **12**

Nova 5: Are micropollutants in urine problematic? On average, for all medicines and hormones ingested, 60–70 % of the active ingredient is excreted in the urine – with major differences between individual compounds. But in a urine-based fertilizer, micropollutants are undesirable. As has been shown by chemical and ecotoxicological analytical tests, these substances can be removed from urine by certain treatment processes. Separate treatment of urine would be beneficial for water pollution control since it would reduce the ecotoxicological hazard potential posed by pharmaceuticals in wastewater by an estimated 50 %. **14**

Nova 6: Urine-based fertilizers? The nitrogen, phosphorus and potassium required for Swiss agriculture is now largely provided by artificial fertilizers. Urine-based fertilizers could be used as a substitute for 15–37 % of the total. In surveys, farmers and consumers are in favour of the idea – provided that health risks are excluded. Experiments from Nova 4 showed that urine-based products are as effective as artificial fertilizers. But before they can be introduced on a large scale, a careful assessment of costs and benefits – and elaborate approval procedures – will be required. **16**

Nova 7: Evaluation. Nova 7 evaluates the impacts of the NoMix technology on urban wastewater management, focusing on two aspects – water pollution control and nutrient recycling. Essentially, a positive view is taken of the new concept – both globally and with regard to Europe. The NoMix technology increases the energy efficiency of the entire system, compared with conventional processes. In addition, it has the potential ultimately to become economically competitive. **18**

Nova 8: NoMix technology for fast-industrialising countries? The introduction of flush toilets in fast-industrialising countries often has a devastating impact on the environment, owing to the lack of appropriate wastewater treatment measures. In the Chinese city of Kunming, situated in the basin of the heavily polluted Lake Dianchi, the potential for treatment at sewage plants is virtually exhausted. If water quality is to be improved, measures such as urine source separation will be required. Stakeholders' attitudes towards the NoMix technology are highly positive – which could pave the way for the large-scale implementation of this system. **20**

Pilot projects: Does NoMix work in real life? Pilot projects involving NoMix toilets are challenging, since these lavatories do not (yet) function as smoothly as conventional models. However, to permit further development, they need to be tested in practice. In Switzerland, four pilot projects were carried out in apartments and public buildings. It was concluded that while it is certainly possible to introduce NoMix toilets, close monitoring of the process is required. In addition, projects in private households are more problematic than in public settings. The experience gained is of great importance both for the development of the technology and for practical purposes. **22**

Practical guide: Would a NoMix toilet be a suitable option for me? NoMix is not yet a mature technology. Certain elements of the system, such as urine treatment, have not progressed beyond the laboratory stage. While the sanitary technology is already available, NoMix toilets do not meet the standard of conventional models in various respects, and they require careful maintenance. A NoMix toilet should therefore only be installed after due consideration of all aspects, and the project objectives should be clearly defined from the outset. The experience gained from Novaquatis can help to ensure that NoMix installations are properly planned. **24**

Publications **26**

People in charge **29**

Beyond end-of-pipe solutions: There are alternatives to wastewater treatment plants for pollution control (Photo Abwasserverband Altenrhein)

Green isn't always beneficial: The NoMix technology could rapidly help to resolve nutrient overload issues in coastal waters (Photo Keystone)

Introduction

Research background

(Tove A. Larsen, Judit Lienert)

Urine source separation is based on a simple insight: most of the nutrients in wastewater – about 80 % of the nitrogen and 50 % of the phosphorus – derive from urine, which itself accounts for less than 1 % of the total volume of wastewater. In the twentieth century, wastewater treatment plants in Europe were expanded specifically to deal with these nutrients, as they produced toxic effects (e.g. ammonium in rivers) or excessive algal growth (e.g. phosphorus in lakes). At treatment plants, major efforts were undertaken to precipitate phosphorus, to convert ammonium to nitrate and to then eliminate the latter.

The "NoMix technology" concept is also simple: urine is collected in the front compartment of specially designed toilets and drained, with a little flushing water or even undiluted, into a local storage tank. The back compartment of these toilets operates on the same principle as conventional models; the waste matter collected is flushed into the sewers with water. One of the Novaquatis research topics was how urine is to be subsequently managed: the nutrients nitrogen and phosphorus are used to produce a fertilizer – or are removed by processes similar to those applied at wastewater treatment plants.

Separating urine from wastewater would offer various advantages: wastewater treatment plants could again be built on a smaller scale, and at the same time waterbodies could be more effectively protected from nitrogen and phosphorus inputs. The nutrients could be recycled to agriculture, and the micropollutants in urine – hormones and pharmaceutical residues – could be removed without being mixed with wastewater. Urine source separation would thus clearly increase the flexibility of wastewater treatment. In the face of global water scarcity, the NoMix technology also represents an excellent way of improving the quality of reused water.

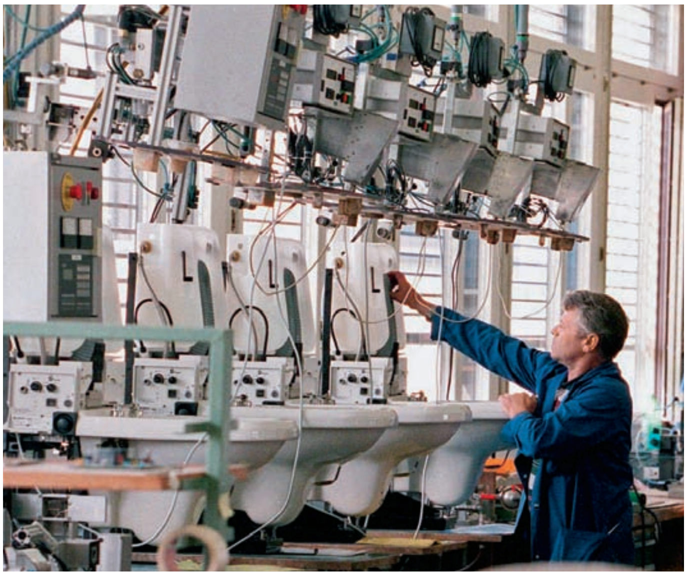
The NoMix technology has major potential. However, the costs need to be competitive with conventional technologies, since problems of water pollution control and phosphorus recycling to agriculture can often also be addressed using conventional methods.

In Novaquatis, we studied whether, in what form and in what circumstances the NoMix technology is a viable option. As a wide range of questions are involved, the projects were organized into work packages reflecting the stages of a possible nutrient cycle. An overview is given on pp. 2–3, and further details can be found in the individual Novaquatis publications (see pp. 26–28).

Results and synthesis

Gratifyingly, the NoMix technology meets with a high level of approval among the public. All the people surveyed in Novaquatis were familiar with and had used the still-immature technology. Although they recognized the drawbacks of today's NoMix toilets, the overwhelming majority found the basic idea convincing (Nova 1). Practitioners also show considerable interest: in Canton Basel-Landschaft, for example, large-scale pilot projects were successfully conducted (Nova PP). With regard to conservation of resources, the NoMix technology also performs well: it has the potential to make a major contribution to water pollution control in an energy-efficient manner. In addition, in areas of nutrient scarcity, urine represents a local nutrient resource (Nova 7).

The difficulties are in the detail, and urine transport proved to be the most problematic point. Installing new pipes or transporting urine by tanker from basement storage tanks for centralized treatment would be a complex and costly undertaking. In Novaquatis, we elaborated low-cost solutions for transporting urine via the existing sewer system (Nova 3). However, despite their potential, they failed to convince the project partners from the sanitary technology industry. These approaches are too closely tailored to Swiss conditions and are also only suitable for relatively small catchment areas. The sanitary industry therefore considers the market potential to be too low to justify investments in the NoMix



Major potential: Urine source separation could spell big business for the sanitary industry (Photo Keystone)

Problem or opportunity? Nutrients from urine are unwelcome in waterbodies, but useful as fertilizers (Photo Andri Bryner)

technology (Nova 2). Improved sanitary technology is, however, indispensable; although pilot projects can be carried out with today's NoMix toilets – larger-scale demonstration projects are not feasible (Nova PP). The objections raised by the sanitary industry will thus have a decisive influence on future developments.

At the same time, literature studies (Nova 7) indicated the huge potential of the NoMix technology from a global perspective. Coastal waters in particular are severely threatened by nutrient overload. As a result of explosive population growth in these regions, the problems associated with nutrients from wastewater are becoming increasingly prominent on the global agenda. Greater elimination of nutrients is required – which is at present being carried out almost exclusively in industrialized countries. In areas currently lacking a fully developed infrastructure, the NoMix technology can protect water resources more rapidly and effectively than the expansion of sewers and treatment plants. The potential of the NoMix technology in cases where acute population pressures give rise to intractable water pollution control problems was impressively demonstrated by the example of China (Nova 8).

Ultimately, the key issues are cost-effectiveness and the technical and organizational possibilities of urine source separation. If urine could be readily transported, centralized urine treatment would be the option of choice. Methods already exist (Nova 4), and processes such as phosphorus precipitation and biological nitrogen elimination can be applied much more cheaply and energy-efficiently to concentrated urine than to wastewater. Great potential also attaches to methods for the recovery of nitrogen and elimination of micropollutants – pharmaceuticals and hormones excreted by humans and detectable in waterbodies. Urine in wastewater accounts for an estimated 50 % of the ecotoxicological hazard posed by these substances (Nova 5).

Given the difficulties and/or cost of transport, the potential and cost-effectiveness of decentralized processes need to be considered. Urine treatment on site appears to be an attractive option. However, it was not possible within the Novaquatis project to study decentralized processes in detail. Here, too, the combination of phosphorus precipitation and biological nitrogen elimination would certainly be a promising approach. We are confident that mass production could make decentralized processes economically attractive for the sanitary and other industries. More problematic, in our view, is the stability of decentralized technologies and the level of maintenance required, especially in the case of biological processes. To facilitate the adoption of the NoMix technology, the two types of solution could be pursued in parallel. In view of Eawag's scientific expertise, we are better qualified to develop stable biological processes and solutions for the organizational problems of decentralized treatment than to identify new options for urine transport.

Conclusions

The Novaquatis research showed that the NoMix technology could represent a valuable alternative to nutrient elimination as practised today – provided that one of the two fundamental problems is solved: either an attractive, widely applicable and low-cost solution needs to be found for urine transport, or stable and cost-effective technologies need to be developed for decentralized treatment.

Water pollution due to nutrient emissions is an increasingly serious problem worldwide, and we are convinced that it is worth seeking solutions. However, to be competitive, innovations require large markets. It may therefore be advisable initially to develop technologies for fast-growing urban areas where nutrient elimination at wastewater treatment plants is inadequate or non-existent. In this way, the NoMix technology could rapidly and effectively help to resolve global water pollution issues. This would require the development of attractive and economic technologies – e. g. by Swiss companies, which increasingly operate in global markets. As solutions of this kind also represent a realistic option for industrialized countries, implementation of the NoMix technology in demonstration projects would make sense here, too. In the long term, Swiss waterbodies would also benefit from the widespread application of this system.

A door to the future? (Photo Yvonne Lehnhard)

Work package Nova 1

Acceptance

Research background

Nova 1 focuses on peoples' attitudes towards the NoMix technology. To date, new technologies have been developed by wastewater management experts without the participation of the public. However, wastewater separation in private bathrooms concerns every individual. Accordingly, both practitioners and users of NoMix toilets were involved at a very early stage of the Novaquatis research programme in order to determine how this innovation is viewed by the public.

Nova 1 involved scientific studies accompanying all the pilot projects in Switzerland. It identified the deficiencies of the NoMix technology and explored questions such as: Are NoMix toilets accepted? Is the design well received? Do the NoMix toilets smell unpleasant? Do users adapt their behaviour? How can the NoMix technology be diffused? What factors would promote the success of further NoMix pilot projects?

Nova 1-1: Consumer attitudes

(Claudia Pahl-Wostl)

Initial data on the acceptability of NoMix toilets in households was provided by a citizen focus group study involving 44 volunteers [1]. The participants were introduced to the complexities of urine source separation with the aid of an interactive Web tool (www.novaquatis.eawag.ch/tool/index_EN) and took part in moderated group discussions. In addition, they visited a NoMix toilet at Eawag.

The most important findings were that 79 % believe the NoMix toilet to be a good idea, and 84 % would move into an apartment fitted with a NoMix toilet – although the costs, maintenance and cleaning efforts required should not be significantly higher than for conventional toilets. Food produced with urine-based fertilizers would be bought by 72 %, provided that health risks are excluded.

Relatively little importance tends to be attached by the participants to sustainable development – e.g. closing of nutrient cycles. More important, in their view, is knowledge of any health risks associated with micropollutants in urine-based fertilizers. Consequently, efforts to minimize such risks are of the greatest relevance in ensuring that the NoMix technology is accepted by consumers.

Many of these findings are confirmed by the quantitative surveys conducted for the pilot projects in public buildings. However, the qualitative results from Nova 1-2 and the pilot project in households indicate that having a NoMix toilet in a private bathroom is not, in practice, unproblematic.

Nova 1-2: Cultural psychology

(Ruth Kaufmann-Hayoz, Kirsten Thiemann)

Nova 1-2 forms part of a doctoral thesis on sustainable product design [2]. On the basis of theoretical considerations and a case study, the relevance of technological innovations to well-being was investigated. As well as exploring historical, collective/cultural developments in the sanitation field and personal bathroom culture, the case study was concerned with the introduction of NoMix toilets at a vocational college and in four private apartments.

As shown by the theoretical investigations, it is difficult to introduce technological innovations that are not in conformity with human culture. One problematic aspect of this process is the sense of being subject to the will of others, e.g. if NoMix toilets are installed in an apartment without the tenants' explicit consent.

This experience in private apartments led to specific recommendations for the improvement and widespread acceptance of the NoMix toilet. The residents' reactions varied widely: some are sceptical, others approve of the NoMix toilet, particularly for environmental reasons, and are happy to use it. Usage of the NoMix toilet is heavily dependent on individual factors such as habits or ergonomics. While some men always sit to urinate, others never do so. The correct sitting position is difficult for many women and especially for children to adopt. The cleaning effort required is generally considered to be relatively large. In addition, it would be ideal if it were possible to select from a range of NoMix toilets with a variety of colours, designs, sitting positions and flushing systems.

Gentlemen, please be seated: The NoMix toilet only works if it's correctly used – but you're allowed to read the paper (Photo Ruedi Keller)

And, how was it? For 80 % of the users surveyed, the NoMix toilet is at least as good as conventional models (Photo Ruedi Keller)

Nova 1-3: Acceptance and diffusion

(Judit Lienert, Tove A. Larsen)

Nova 1-3 used quantitative studies to assess the acceptance of the NoMix technology among larger target groups and investigated how it could be further diffused. Surveys were conducted for all three Swiss pilot projects in public buildings: at a vocational college (534 respondents), at Eawag (715) and at the Basel-Landschaft cantonal library (501). The results are representative for users of buildings of this kind (e.g. vocational college students in German-speaking Switzerland).

Acceptance levels were very high in all cases. Urine source separation was considered a good idea by 72 % of respondents at the vocational college and Eawag, and 86 % would move into an apartment fitted with a NoMix toilet [3, 4]. Around 80 % rated NoMix toilets as equivalent or superior to conventional toilets with regard to design, hygiene and odour. While the NoMix technology only works if the toilet is correctly used, most of the respondents were prepared to adapt their behaviour; for example, 72 % sat to urinate. These findings were confirmed by the survey at the BL cantonal library (not yet published).

Theoretically objective factors (e.g. odour) are often subjectively perceived in practice. Acceptance thus depends not only on clean sanitary facilities but also on information, discussions with peers and personal attitudes. Effective communication therefore has a decisive influence on project outcomes.

The NoMix technology is linked to the entire wastewater management system – from toilet to treatment plant. A high level of acceptance among toilet users in itself offers no guarantee that the innovation will be widely adopted in practice. What is crucial, rather, is to gain the support of wastewater professionals – as was shown by an analysis based on diffusion theory [5]. Urban wastewater management experts will have to introduce the new system and bear many of the consequences. Scientists, for their part, will need to provide mature solutions capable of winning the commitment of professionals to further develop the NoMix system in practice.

Conclusions

The results from Nova 1 make it possible to assess how the Swiss public could react to the NoMix technology. It will probably be widely accepted if it meets modern sanitary standards and is safe and not too expensive. However, given the drawbacks of current NoMix toilets, large-scale implementation cannot yet be recommended; the toilets first need to be optimized by the sanitary firms (Nova 2). Our experience indicates that while further pilot projects are still possible with the immature technology, careful supporting measures will be required. Such projects are trickier in homes than in public buildings, where maintenance is performed by technical staff. As the next step, diffusion pathways for the NoMix technology should be investigated and market niches identified where it can be implemented and refined. The public is prepared to give this unconventional technology a chance.

The bowl of the future (Photo Yvonne Lehnhard)

Work package Nova 2

Sanitary technology

Research background

The modern water-flush NoMix toilet was invented in Sweden in the 1990s. The principle is straightforward: when the user sits on the toilet, urine is collected at the front and drained into a separate tank, while at the back the faeces are flushed away in the normal manner. The appliance thus, in effect, consists of a toilet with a built-in urinal.

But this simple principle involves certain practical difficulties. As in the case of waterfree urinals, mineral deposits – popularly known as urine scale – build up over time, and pipes may be blocked as a result.

This and other sanitary technology-related problems raise a number of questions: How can clogging of the pipes be avoided? On a NoMix toilet, what sitting position is both comfortable and functional? Does separation work in practice? Does this kind of toilet fit in with a modern bathroom, or does it look anachronistic and old-fashioned? If necessary, how can NoMix toilets be improved?

In the overall NoMix system, the new toilet technology plays a significant role. Answers to the above questions were sought in several Novaquatis work packages: Nova 1 (how do users react to the technology?), Nova 2-1 (how can innovations be achieved?), Nova 2-2 (how does precipitation arise?), Nova 3 (is source separation successful?), Nova PP (can pilot projects already be carried out with existing NoMix toilets?).

A number of conclusions can be drawn from the various projects: although the existing NoMix toilets are not perfect, it is certainly possible to use them in pilot projects (Nova 1, Nova PP). The major problem of precipitation remains unresolved (Nova 2-2). There are thus good reasons to pursue further development of the NoMix toilets (Nova 2-1).

Nova 2-1: Cooperation with the sanitary industry

(Tove A. Larsen, Judit Lienert, Bernhard Truffer)

In the 1990s, Novaquatis participated in the development by Roediger (www.roevac.com) of a new NoMix toilet permitting the collection of undiluted urine. This appliance was used in Novaquatis pilot projects, and the new Eawag building is fitted exclusively with the Roediger NoMix toilet, in addition to a variety of waterfree urinals. The experience gained through Novaquatis was communicated to the manufacturer and should now provide a basis for the development of a new-generation, functionally enhanced Roediger NoMix toilet (cf. "Practical guide").

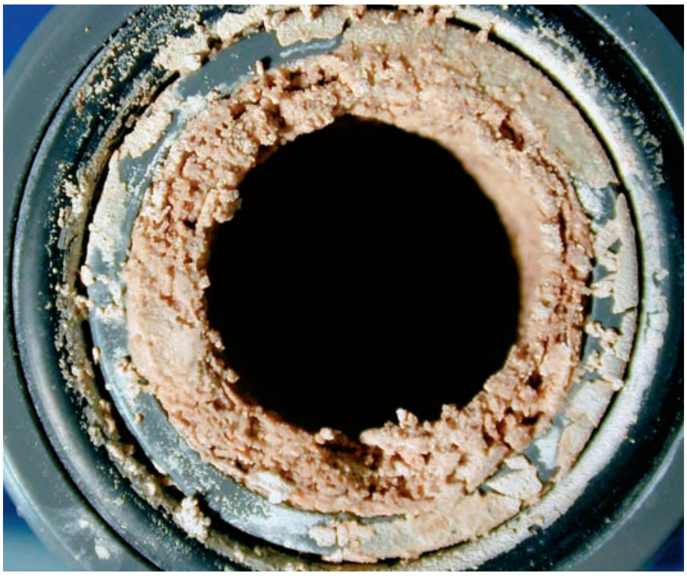
With today's sanitary technology, pilot projects are practicable at workplaces, for example, but in private households they remain problematic (Nova PP). However, the system can only be developed to maturity through large-scale pilot and demonstration projects. In round-table discussions at four workshops involving representatives of the sanitary and wastewater sector, we explored what was required to enable an optimal NoMix toilet to be introduced. It transpired that, for the companies concerned, a clear definition of the initial markets is indispensable. These also need to be sufficiently large to make commercial production worthwhile. Major markets are to be found where major problems exist. As well as rapidly expanding cities in fast-industrialising countries (Nova 8), this could include water-scarce regions such as Australia or China. In contrast, the step-by-step approach envisaged in Swiss transition scenarios (Nova 3) is unattractive for the industrial partners, as the market is judged to be too small. In addition, the development process is complicated by the large number of parties involved. As previously noted [1], if companies are to be prepared to make more substantial investments, it is crucial that wastewater professionals should begin to take a much greater interest in the NoMix technology. Essentially, the sanitary industry is interested and considers the task to be feasible. However, all the solutions entail additional costs, and since these are incurred by households, while the savings are made by local authorities, the costs would have to be transferred through an ingenious financing model.

Nova 2-2: Precipitation

(Kai Udert, Tove A. Larsen, Willi Gujer)

Nova 2-2 consisted of a doctoral thesis investigating precipitation in toilets and in waterfree and conventional urinals with the

Making scents: A deodorant block that absorbs ammonia can be used as a freshener (Photo Ruedi Keller)



Unwelcome deposits: Pipes can be blocked by urine scale (Photo Kai Udert)

aid of field measurements, laboratory experiments and computer simulations [2–6]. Precipitates accumulating in pipes and siphons can lead to blockages after only a few thousand uses.

When urea from urine is degraded (hydrolysed) by bacteria, the pH rises sharply, up to 9 or more. As a result of shifts in the buffer systems, the solubility product of various poorly soluble salts is exceeded, leading to crystallization. This is true in particular of struvite (magnesium ammonium phosphate, MAP) and various calcium phosphates.

Ureolytic bacteria mainly grow in the pipes and are flushed into the collection tank. After only a few days, the urea is completely degraded. In undiluted urine, hydrolysis of only 8 % of the urea is sufficient to increase the pH to almost the maximum value, with 95 % of the possible precipitation being attained as a result.

Following the initially favourable experience with waterfree urinals, it was long believed that no salts would crystallize from undiluted urine. However, field measurements indicated that the opposite is the case – i. e. blockages occur mainly when the urine is only slightly diluted or completely undiluted. Calculations based on computer modelling showed that less precipitation of salts per volume occurs with diluted than with undiluted urine. The least precipitation occurs when rain water is used for flushing, as this avoids the addition of either calcium or magnesium. Although the quantity of precipitates is one of the main factors giving rise to blockages, it is not the only one. Also critical are narrow diameters and prolonged residence of urine in pipes and siphons.

Conclusions

The combined results from Nova 2 provide a number of indications as to what could be done to bring an improved NoMix toilet to the market, and what fundamental changes would be required. Although urine dilution reduces blockage-related problems, it entails the use of larger urine tanks. In addition, it complicates urine treatment. A better solution might therefore be the deliberate promotion of unavoidable precipitation in undiluted urine – in a replaceable unit in the toilet. This principle is already applied by the industry in various waterfree urinals. For the NoMix toilets available today, however, the problems need to be solved pragmatically or alleviated, e. g. by rainwater flushing systems (cf. "Practical guide").

The sanitary industry is in principle interested in bringing good-quality NoMix toilets to the market and is convinced that this goal is achievable. However, as they are more expensive than conventional toilets, wastewater professionals, for their part, need to identify sizeable markets that would make it worthwhile for the industry to become involved and to undertake costly development work (cf. Nova 7).

Urine on tap: Collection tank at Eawag (Photo Ruedi Keller)

Work package Nova 3

Storage and transport

Research background

Nova 3 is concerned with the transport of urine from the NoMix toilet and a local tank to a central treatment plant. Various options exist for transporting locally stored urine – tankers, separate pipes, or the existing sewer system. The latter could be used at a relatively low cost, for example, by transporting urine at night – i. e. at a time when in many catchments only small amounts of water, largely unpolluted, flow through the sewers [1, 2]. However, this strategy involves certain risks, as it would entail the passage of highly concentrated urine through the sewer system for a short time. Thus, in the event of unforeseen excessive rainfall, large quantities of urine could enter receiving waters untreated. In addition, odour nuisances could arise. As a transition scenario, therefore, Novaquatis investigated another option for transporting urine through the sewer network: the nitrogen load is distributed over 24 hours, leading to improved utilization of capacity at an existing wastewater treatment plant (Nova 3-1). This strategy would make it possible to gain experience concerning the reliability of rain forecasts without running any major risks, since at no time would the amounts of urine passing through the sewers be larger than at present.

An alternative to the difficulties of urine transport would be local treatment, based on the results obtained in Nova 4.

Nova 3-1: Urine source separation and "waste design"

(Wolfgang Rauch, Willi Gujer, Tove A. Larsen)

The concept of "waste design" involves retaining portions of the domestic or industrial wastewater that arises and only transporting it when capacity is available for the processing of these streams at a wastewater treatment plant [3]. This system is particularly appropriate in the case of urine: because most people use the toilet when they get up, a "morning peak" of urinary nitrogen is recorded at wastewater treatment plants. To allow this peak load to be processed, treatment plants currently have to be designed with significantly larger dimensions than would actually be required – with a corresponding increase in construction costs. If household urine was stored and then released in a controlled manner throughout the night, treatment plants would be exposed to more evenly distributed nitrogen loads. In addition, it would be beneficial to retain stored urine during periods of heavy rain, as in such cases – at present – some wastewater is discharged untreated into receiving waters via combined sewer overflows.

Nova 3-1 elaborated a virtual case study based on stochastic modelling. Using data from the Zurich region, it assumes a complete changeover to NoMix toilets. According to this study, a 10-litre storage tank integrated into each NoMix toilet and a simple control strategy would yield the following results: firstly, a reduction of more than 50 % in the annual volume of urine released by combined sewer overflows and, secondly, a decrease of approx. 30 % in the peak load of nitrogen under dry-weather flow conditions. The first of these may be an economically attractive option, as it reduces inputs of toxic ammonia to surface waters during rainfall [4]. The second leads to an increase in the performance of a nitrifying wastewater treatment plant commensurate with the reduction in peak load. In certain cases, the (costly) expansion of existing treatment facilities could thus be effectively avoided or deferred ([5]; see also Nova 3-3 and 7-2).

Nova 3-2: Storage and transport

(Luca Rossi, Judit Lienert, Tove A. Larsen)

An extensive series of measurements provided information on the functioning of the NoMix technology under real-life conditions [6]. The findings of this research are important as they indicate the need for urine to be correctly collected in the NoMix toilets and drained into the storage tank. Household measurements revealed that the urine yield was only 60–75 % of the amount expected, thus showing where practical improvements to the NoMix toilets are possible. In the institutional setting, e. g. at Eawag, considerably more urine was collected with the NoMix toilets. However, the potential for improvement can only be estimated for the women's toilets, since the men use the urinals in most cases. Further measurements indicated that in 55–60 % of flushes, the low water volume button was pressed. In certain households,

Gone but not forgotten: The date and time of each flush are recorded by a digital counter at Eawag (Photo Ruedi Keller)

Community-level toilet usage: Precise data on housing, employment and recreation are required for the microsimulation model (Photo Karin Güdel)

however, the low-flush option was hardly ever used; in the institutional setting, the proportions varied widely. The frequency of flushing in households clearly demonstrated the reason for the "morning peak" in nitrogen levels at wastewater treatment plants: not only is morning urine more concentrated, but flushing is more frequent at this time of day. In addition, marked differences were observed for households between weekdays and the weekend. This coincides precisely with the results of measurements at wastewater treatment plants. The detailed data can be used to help design urine storage tanks for future pilot projects, thereby avoiding the construction of units that are too large – and costly – or too small.

Nova 3-3: Microsimulation model (formerly Nova 7-1)

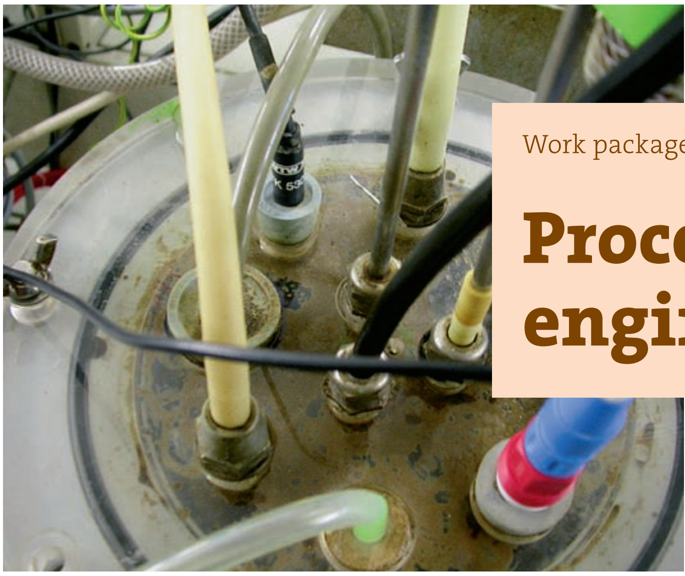
(Christian Spörri, Peter Reichert, Irene Peters, Tove A. Larsen)

A new computer model based on microsimulation was used to evaluate the effects of different strategies for the management of urine tanks [7]. The test region was the catchment of the Ergolz 1 wastewater treatment plant in the canton of Basel-Landschaft. The model is based on census data concerning residents, their workplaces and residential and commercial buildings. It represents people's movements to work, recreational activities and service enterprises. Medical data provided the basis for simulating people's urination patterns and, hence, urine production in individual toilets. Rain forecasts and precipitation data from the region were used to identify optimum tank management strategies, with the aim of achieving the goals defined in Nova 3-1 – levelling out nitrogen loads at the wastewater treatment plant and avoiding urine releases from combined sewer overflows. With a random distribution of NoMix toilets in only 30 % of the apartments and workplaces and a tank capacity of 10 litres, the model generates the following predictions: the peak load entering the wastewater treatment plant is reduced by 20 %, and at the same time urine concentrations in the sewer system during rainfall are lowered by 22 %. More elaborate modelling thus makes it possible to identify better control strategies than the one applied in Nova 3-1, which assumes universal distribution of NoMix toilets.

Conclusions

The key problem for the NoMix technology is how to transport urine from the NoMix toilet to a central treatment plant. Nova 3 shows that a good interim solution can at least be found for urine transport, which optimizes the capacity of wastewater treatment plants – i. e. transport via the existing sewer system, with urine streams distributed over 24 hours. In principle, it would also be possible to discharge concentrated urine through the sewer network in a wave. However, the feasibility of this approach would have to be demonstrated by experience from a large-scale practical project. Implementation of the interim solution would permit such experiments. As an alternative to the difficulties of transport, urine could be treated locally in accordance with the findings of Nova 4.

Practical experience from the pilot projects shows that there is room for improvement in the efficiency of urine source separation in NoMix toilets – a finding that is of particular relevance for the further development of the NoMix appliances.



Biological reactor for stabilization (Photo Yvonne Lehnhard)

Work package Nova 4

Process engineering

Research background

The bulk of the nutrients from human metabolism are excreted in urine – in particular, nitrogen (N), phosphorus (P) and potassium (K). These nutrients are desirable in agriculture, but not in waterbodies (where only K causes no harm). It may therefore make sense to separate urine from wastewater and use it for fertilizer production.

Fresh urine is slightly acidic, with a pH of 6–7. However, the high concentration of biologically degradable substrate promotes rapid bacterial growth. As a result, the chemical composition of urine undergoes significant changes during collection and storage. Since urea is hydrolysed to ammonia and carbon dioxide, the pH rises sharply – to more than 9 (cf. Nova 2). In addition, urine contains organic micropollutants, especially pharmaceutical residues and hormones, which are equally unwelcome in waterbodies and in agriculture (Nova 5).

The various treatment processes serve widely differing purposes: urine can be stabilized and its volume reduced; nitrogen and phosphorus can be recovered or removed; and bacteria, viruses and micropollutants can be eliminated [1]. However, it is not possible to achieve all the different objectives using a single process; a decision is thus required as to what is desirable and what is necessary.

In general, urine treatment may involve biological (Nova 4-1), chemical (Nova 4-2, 4-3) or physical (Nova 4-3) processes. The advantages and disadvantages of the various methods are discussed in detail in [1].

Nova 4-1: Biological processes – stabilization

(Kai Udert, Tove A. Larsen, Willi Gujer)

Nova 4-1 was concerned with the development of a biological process for urine stabilization [2]. Bacteria cultured in a reactor not only decompose organic compounds in urine but also convert a portion of the ammonium to nitrite or nitrate (nitrification). This leads to the production of acid, which lowers the pH of the urine from more than 9 to about 6, preventing losses of ammonia. At the same time, the biological processes eliminate unpleasant odours.

With this process, a solution of ammonium nitrate or ammonium nitrite is obtained. The nitrogen compound ammonium nitrate is a commercial fertilizer. Ammonium nitrite, in contrast, is toxic to soil organisms. However, it can readily be converted to nitrate through chemical oxidation with oxygen at a low pH value [3] or, using another biological process, to a harmless nitrogen gas and water [2].

Nova 4-2: Chemical processes – phosphorus precipitation

(Mariska Ronteltap, Max Maurer, Willi Gujer)

The chemical conditions in stored urine (i. e. high pH values) promote the precipitation of phosphorus in the form of poorly soluble phosphorus-containing salts. This leads to encrustation and clogging of pipes (Nova 2). However, the process can also be used for phosphorus recovery.

With controlled addition of magnesium, phosphorus can be recovered in the form of struvite ($MgNH_4PO_4$, magnesium ammonium phosphate, MAP). This is attractive, as two significant wastewater nutrients (P and N) are thus transformed into a single solid product, which is, moreover, a well-established slow-acting multicomponent fertilizer.

Nova 4-2 investigated in detail the process whereby struvite is produced from urine [4]. It was shown that the rate of phosphorus elimination depends crucially on the degree of dilution, but generally reaches 98 %. The product obtained is largely free of pharmaceuticals and hormones, and no heavy metals could be detected [5].

Although struvite can be used directly as a fertilizer, it is not suitable for further processing in the phosphorus industry [1]. In a Novaquatis follow-up project, other precipitation products are being studied that would be suitable for further processing of this kind. Thus, both options can be kept open.

Murky mixture: Magnesium-chloride is added to urine (Photo Yvonne Lehnhard)

Clean product: A pure nutrient powder is obtained (urine-based fertilizer struvite) (Photo Mariska Ronteltap)

Clean bill of health: Analysis of micropollutants (Photo Yvonne Lehnhard)

Nova 4-3: Physical processes – membrane technology

(Wouter Pronk, Markus Boller)

Nova 4-3 considered various urine treatment scenarios, focusing on membrane technologies. The aims of these methods are threefold: (1) to separate organic micropollutants from nutrients, (2) to concentrate the nutrient solution (volume reduction) and (3) to remove or destroy bacteria and viruses. In addition, micropollutants can also be eliminated via the chemical process of ozonation.

The membrane technology of nanofiltration was tested in the laboratory. The process is only effective if urea in fresh urine is not hydrolysed. If this can also be successfully prevented in practice – e.g. through acidification – nanofiltration can be used to produce a urea solution (without phosphorus). This solution is largely unproblematic: a large proportion of the organic micropollutants can be separated from the nutrients, and bacteria and viruses are eliminated [6]. In the nanofiltration process, the nutrients are not concentrated – in a further project, vacuum evaporation was employed for this purpose. With this process, the volume of a urea solution was reduced by 90 % at 78 °C [1].

Also tested in the laboratory were the membrane-based process of electrodialysis and the chemical process of ozonation. With the aid of electrodialysis, micropollutants can be largely separated from ammonium, phosphorus and potassium, as can microorganisms such as bacteria. At the same time, the nutrient solution is concentrated roughly fourfold [7]. If ozonation is additionally performed, the fertilizer produced is highly likely to be acceptable as regards both hygiene and contamination with pharmaceuticals and hormones.

In a follow-up project, electrodialysis and ozonation are being tested on a pilot scale for the treatment of urine collected at the Basel-Landschaft cantonal library in Liestal [8] (cf. Nova PP). The nutrient solution produced here contains 12 g N, 0.65 g P and 5.7 g K per litre.

Conclusions

The wide variety of urine treatment processes available offers substantial flexibility. For example, if a rural setting calls only for stabilization, to prevent the release of ammonia when fertilizer is applied, a one-step biological treatment should be sufficient. But if nutrients are to be recycled in a metropolis – as would be advisable in areas with a general lack of fertilizers – the demands are higher, and various processes will need to be combined. Nutrients can, however, also be eliminated – e.g. to protect sensitive receiving waters from excessive nutrient loads.

All the processes will require further development before they can be implemented in practice. But thanks to the Nova 4 research, we now know precisely what processes are currently available, for what purposes they are suitable, and in what respects they need to be optimized.

In many cases, separate removal or recycling of nutrients is preferable to the existing practice. This also applies to the energy requirements associated with these processes [1, 9].

Painkillers end up in waterbodies (Photo Yvonne Lehnhard)

Work package Nova 5

Micropollutants

Research background

Medicines and hormones can be detected in wastewater treatment plant effluents, in surface waters and in groundwater – i. e. they are only partly removed by wastewater treatment processes. This may be problematic; for example, reproduction in fish is influenced by the highly bioactive hormones. Although the severity of the problem remains unclear, caution is required given the sheer variety of substances in use – in 2005, 4727 human medicines were registered in Switzerland.

Many substances ingested by humans are transformed in the body (metabolized) and excreted in the urine or faeces. This is a drawback if fertilizer is produced from urine, since micropollutants are also undesirable in agriculture (Nova 6). Accordingly, the removal of such substances was one of the aims of the treatment processes studied in Nova 4. In Nova 5, ecotoxicological and chemical analytical methods were developed in order to evaluate the quality of the urine product. Urine source separation would be beneficial in terms of water pollution control, as the substances contained in urine would thus be prevented from entering wastewater streams.

Nova 5-1: Ecotoxicological tests for urine quality control

(Beate Escher, Rik Eggen, Nadine Bramaz)

In Nova 5-1, a test battery was developed with the aim of determining *in vitro* whether pharmaceuticals in urine pose an environmental risk (ecotoxicological hazard) [1, 2]. The battery includes non-specific tests, showing a reaction to general cell damage [3]. In addition, specific tests indicate, for example, whether a sample contains substances that are hormonally active, attack genetic material or disrupt plant photosynthesis [4]. Thus, rather than measuring a single drug and its metabolites, tests of this kind determine the overall effect. To rule out interference from natural urine components (e. g. salts, high pH), a solid-phase extraction method was developed for the preparation of samples [1].

The test battery permits effective quality control of the treatment processes with regard to the removal of micropollutants (Nova 4). For example, while the efficiency of the bioreactor was found to be inadequate [5], struvite precipitation was shown to be highly efficient: the micropollutants studied were almost completely removed. Nanofiltration removed 50–90 % of the toxicity, and ozonation – depending on the ozone dose – 55–99 %. It was concluded that the effects of the treatment processes varied widely, and the results of the various bioassays were sharply divergent. The methods tested thus remove different substances to different extents.

Nova 5-2: Measuring hormones in urine by chemical analysis

(Marc Suter, René Schönenberger)

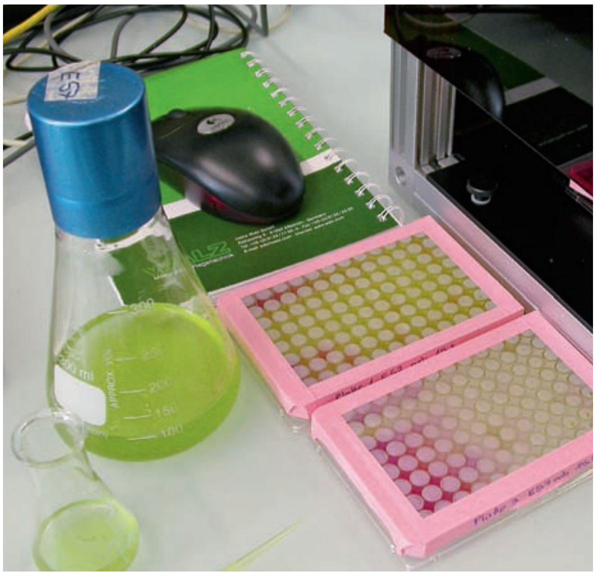
In the EU COMPREHEND programme, analytical tools were developed for the detection of endocrine-disrupting substances in effluents from wastewater treatment plants across Europe [6]. In Nova 5-2, one of these new chemical analytical methods (liquid chromatography/mass spectrometry/mass spectrometry; LC/MS/MS) was adapted so as to permit measurement of hormones in urine. Urine in the reactors from Nova 4 was spiked with known quantities of the natural female hormone estradiol and the synthetic ethinylestradiol (active substance in oral contraceptives) [5]. Can these hormones be eliminated? Electrodialysis removed 98 % of the estrogens. However, as a large proportion is retained by the membranes, these have to be cleaned in a separate step. After 24 hours, the bioreactor had removed 89 % of the natural estradiol, but only 55 % of the synthetic hormone used in contraceptives. Hormones were no longer detectable in struvite, and estrogenic activity was also eliminated with ozonation.

Nova 5-3: Measuring pharmaceuticals in urine by chemical analysis

(Alfredo Alder, Christa McArdell, Elvira Keller)

The EU Poseidon project (http://poseidon.bafg.de/) studied technologies for the removal of pharmaceuticals at wastewater treatment plants. In Nova 5-3, the chemical methods developed

Test battery: The hand is holding the algal assay (Photo Yvonne Lehnhard)



True colours: Reddish colour changes of the YES test indicate the presence of estrogens (Photo Yvonne Lehnhard)

High tech in the lab: Samples are loaded for chromatography (Photo Y. Lehnhard)

in the Poseidon project for wastewater were to be adapted for the analysis of urine. However, control measurements indicated that this approach was unsuitable for this purpose. Using other methods from Nova 4-3, however, it was possible to measure individual substances [5].

Nova 5-4: Contribution of urine source separation to water pollution control

(Judit Lienert, Beate Escher, Karin Güdel, Timur Bürki)

Nova 5-4, which was co-financed by the Federal Office for the Environment (FOEN; www.bafu.admin.ch), investigated whether urine source separation can contribute to water pollution control. The differences observed between 212 active ingredients (corresponding to 1409 pharmaceutical products) were immense. For example, urinary excretion of X-ray contrast agents was 90–100 %, compared with only 6 % for one cancer drug and 98 % for another. On average, 64 % of the active ingredient ingested was excreted in the urine. Also on average, 42 % was transformed in the body and excreted as metabolites, which were mainly found in the urine [7].

Using a screening method, it was possible to assess the environmental hazard posed by excreted pharmaceuticals. The method is based on literature data, e. g. on the chemical properties and metabolism of the active ingredient, and on the quantities of medicines sold. It was developed with reference to drugs used in cardiology (beta-blockers). In the case of these agents, the Nova 5-1 test battery revealed an unexpected effect: they inhibit the photosynthesis of algae [4]. The method was subsequently applied to the (avian) influenza drug tamiflu, which is metabolized to 75 % in the human body (data not published). For tamiflu, the ecotoxicological hazard estimated with the screening method would appear to be low.

Another 42 substances were then investigated [8]. In 34 cases, the toxic potential was reduced by metabolism in the human body. The ecotoxicological hazard of each of these substances after being metabolized tended to be low. However, there were some exceptions: ibuprofen, in particular, which is found in numerous analgesic drugs, poses a relatively high risk to the environment. Considerable differences were found in the site of activity: some substances developed their toxic potential mainly in the urine, others in the faeces. While the screening method has its limitations, we estimate on the basis of the limited data known to us that the ecotoxicological hazard potential associated with pharmaceuticals in urine and faeces is of about the same magnitude.

Conclusions

It was demonstrated by chemical and ecotoxicological analysis that pharmaceuticals and hormones can be removed from urine with the aid of treatment processes studied in Nova 4. However, not all methods were equally effective [5]. Many pharmaceuticals occur only in trace amounts that can barely be measured by chemical analysis. Chemical methods are valuable, for example, in characterizing the degradation processes of individual substances. Ecotoxicological tests are suitable for estimating the overall toxicity of natural urine samples [1, 2]. However, it needs to be borne in mind that, in certain bioassays, effects may be produced merely by natural urine components [5].

Urine source separation can help to protect waterbodies from micropollutants. However, even if it were to be fully implemented, not all pharmaceuticals and hormones would be prevented from entering wastewater [7]. On the basis of estimations and limited data, we assume that urine source separation would remove about half of the ecotoxicological hazard potential [8].

Pot plant: Ryegrass (Photo Jürgen Simons)

Work package Nova 6

Agriculture

Research background

In Switzerland, nutrients from human urine could supply around 37 % of the nitrogen, 20 % of the phosphorus and 15 % of the potassium demand currently met by artificial mineral fertilizers [1]. The original aim of Nova 6 was to study the possibilities and problems of this type of urine recycling. Unfortunately, funding could not be secured for these research projects. However, with the aid of external partners, two key questions were investigated: Would a urine-based fertilizer be well received by farmers and the public? And is treated urine as effective as artificial fertilizers?

Nova 6-1: Is urine-based fertilizer found acceptable?

(Judit Lienert, Michel Haller, Alfred Berner, Michael Stauffacher, Tove A. Larsen)

In 2000, 467 questionnaires were sent to Swiss farmers, with four categories being distinguished: organic or integrated (IP) farming, and with or without vegetable production [1]. The response rates for the individual groups varied and were low overall (127 responses received). Although the results are thus not representative, they do provide important initial evidence.

Urine-based fertilizers were favourably viewed by 57 % of respondents, and 42 % would purchase such products – especially those who already buy additional fertilizers. As this mainly applies to IP and vegetable farming, these would probably be the most promising markets. However, no farmers would be prepared to pay a higher price than for conventional fertilizers. Most prefer a nitrogen fertilizer in the form of ammonium nitrate. In addition, a granulate is preferred to a liquid formulation, and a urine odour is rejected. A key requirement is that the urine-based fertilizer should be hazard-free, with 30 % expressing concerns that it could contain micropollutants, e. g. pharmaceutical residues.

Consumers' attitudes appear to be similarly favourable (Nova 1). However, this group would likewise only buy food grown with urine-based fertilizers if it was hazard-free. High priority is therefore given to the elimination of pathogens and medicines from urine – for example, among the participants of a focus group study (Nova 1, [2]). Of 501 people surveyed at the BL cantonal library (Nova PP), two thirds would also use a urine-based fertilizer in their own garden or buy vegetables to which it had been applied (results not yet published). The other third was opposed to urine-based fertilizers on the grounds of distaste or health concerns.

Nova 6-2: Pot experiments with urine-based fertilizers

(Jürgen Simons, Joachim Clemens)

In a Bonn University dissertation project, the suitability of Nova 4 urine products as fertilizers was assessed in greenhouse experiments [3, 4]. Ryegrass *(Lolium multiflorum italicum)* and red clover *(Trifolium pratense)* were used as test plants. The study compared seven different nitrogen-enriched substrates – including untreated urine and the products of Nova 4-1 (bioreactor) and Nova 4-3 (nanofiltration, electrodialysis) – with an artificial fertilizer (calcium ammonium nitrate). In addition, five phosphorus fertilizers, including struvite (MAP; Nova 4-2), were compared with the artificial fertilizer superphosphate.

Plants treated with urine-derived nitrogen showed practically the same yield as those receiving the mineral fertilizer, with the same uptake of nitrogen from the soil. Differences between the products tested can be explained by differences in pH and the resultant ammonia losses. Thus, plants fertilized with acidified urine (pH 4) showed a significantly higher yield than those receiving untreated urine (pH 9).

The phosphorus fertilizers tested differed from the artificial fertilizer – both in yield and in phosphate uptake. Phosphates precipitated with magnesium, including the struvite from Eawag (MAP), produced comparable values to the artificial fertilizer. In contrast, phosphate fertilizers from sewage sludge – precipitated with iron, for example – produced significantly poorer results. In general, the struvites from decentralized wastewater treatment were more homogeneous than those from the wastewater treatment plant – with regard to composition and fertilizer efficiency. As the differences cannot be fully explained, further research is required, e. g. to analyse and optimize the production processes.

The right dose of fertilizer: "Urevit" is carefully measured out (Photo Martin Koller)

Slurry versus urine: Treatment of maize plants in a field test (Photo Martin Koller)

Smart vegetables: Many consumers accept a urine fertilizer (Photo Yvonne Lehnhard)

Nova 6-3: Field tests with urine-based fertilizers

(Martin Koller, Alfred Berner, Wouter Pronk, Steffen Zuleeg, Markus Boller, Judit Lienert)

Following electrodialysis and ozonation treatment, urine from the BL cantonal library is to be used as a fertilizer (Nova PP). In 2006, the Research Institute of Organic Agriculture (FiBL; www.fibl.org) was therefore commissioned by Novaquatis to study the urine's fertilizer properties. The tests were carried out at an IP site – using fodder maize, which has a high nitrogen requirement. Here, the urine-based fertilizer "Urevit" was compared with cattle slurry, "Kompogas" anaerobic digester liquid, commercial organic fertilizer (feathermeal) and synthetic fertilizer (ammonium nitrate). "Urevit" is more stable than untreated urine, the nutrient content is about three times higher, and the product is – as far as is measurable – free of bacteria, viruses and micropollutants.

The key finding is that "Urevit" is suitable for use as a fertilizer. After the main growth period, maize treated with "Urevit" showed the same height and leaf colour as that treated with a mineral fertilizer; both groups were superior to the plants treated with cattle slurry or feathermeal. Since leaf colour in maize is closely correlated with nitrogen supply, "Urevit" and mineral fertilizer initially act equally rapidly. However, the "Urevit"-treated plants – like those receiving "Kompogas" or feathermeal – had a significantly (15 %) lower yield than maize treated with mineral fertilizer. Nitrogen was presumably lost when "Urevit" was applied, but such losses could be controlled by optimizing urine processing and spreading. Today, fertilizers are often applied using trailing hoses. If "Urevit" was distributed to farmers free of charge, the costs of this spreading method would be roughly the same as for ammonium nitrate – making "Urevit" an economically attractive option for farmers.

The Basel-Landschaft utilities agency (AIB; cf. Nova PP) received provisional approval from the Federal Office for Agriculture (FOAG; www.blw.admin.ch) to use "Urevit" as a fertilizer – definitive approval can only be granted when stringent quality requirements are met. As an interim step, the fertilizer could be used for non-agricultural purposes, e. g. for ornamental plants at local horticultural firms.

Conclusions

In the course of Nova 6, important contacts were established with agricultural partners, e. g. the FOAG (Nova 6-3), FiBL (Nova 6-1, 6-3) and Agroscope Reckenholz-Tänikon Research Station (ART; www.art.admin.ch). Representatives of this sector approve of the cautious approach adopted by Novaquatis; in this way, polemical debates – of the kind that led to the ban on the use of sewage sludge in Swiss agriculture – can be avoided. Farmers and consumers (Nova 6-1) are sympathetic to the idea of urine-based fertilizers. However, both groups emphasize that it is essential to eliminate any risks – e. g. posed by micropollutants. Such substances need to be effectively removed (Nova 4). But since absolute safety can never be attained, ecotoxicological studies (Nova 5) in subsequent projects should be accompanied by a broader social debate – also involving agricultural representatives, consumer groups and the major food retailers.

Thanks to Nova 6, we now know how farmers and the public can be expected to react, and what steps should be taken in introducing a urine-based fertilizer on the Swiss market. We also know that urine-based products are suitable for use as fertilizers and are generally comparable to artificial fertilizers. Still, fertilizers are currently very inexpensive – at least in industrialized countries. The question therefore arises to what extent costly fertilizer production processes, as implemented on an experimental scale in Novaquatis, would be worthwhile. In the numerous parts of the world (e. g. Africa, China) where nutrients are in short supply, however, the case for using urine as a fertilizer is compelling.

Stakeholders discuss the NoMix technology (Photo Karin Güdel)

Work package Nova 7

Evaluation

Research background

Nova 7 is concerned with evaluating the advantages and disadvantages of the NoMix technology. Technology assessments are always difficult – especially when the technologies in question do not yet exist. For example, how are we to determine overall costs or energy consumption merely on the basis of prototypes in the laboratory? And how can we give due consideration to all the various aspects? Nova 7-1 summarizes the main results of Novaquatis obtained in the course of the entire project. Nova 7-2 tests a methodological approach comparing various NoMix options with a conventional solution for a specific scenario. The different options are based on the preferences of actual stakeholders.

Nova 7-1: Evaluation of the NoMix technology

(Tove A. Larsen, Max Maurer, Kai Udert, Judit Lienert)

The NoMix technology makes it possible for nutrients to be comprehensively eliminated or recycled through a relatively minor modification to the wastewater system [1]. However, whether – and in what form – it is worth implementing the technology depends largely on the existing infrastructure and environmental situation. The NoMix technology is particularly valuable where nutrient emissions are subject to stringent regulations. It is also to be recommended in regions where it makes economic sense to recycle nutrients to agriculture.

The importance of the NoMix technology is assessed on a broad scientific basis in [2]. In global cycles, nutrients from human metabolism do not play a significant role. The nitrogen cycle is dominated by biological and industrial nitrogen fixation. Human excretion only accounts for about 5 % of the total production of reactive nitrogen. In the global phosphorus cycle, agriculture is probably the dominant factor. With regard to water resources, by contrast, phosphorus and nitrogen inputs from wastewater are of major importance. It is therefore worth looking for efficient ways of removing these nutrients – especially in densely populated areas where wastewater constitutes the largest proportion of nutrient flows or where conventional technology is overstretched. In Switzerland, one example would be Lake Greifen, where the quality targets specified for phosphorus cannot be complied with. Internationally, a good example is the Chinese city of Kunming (cf. Nova 8). Globally, nutrients from wastewater will play an increasingly important role as a result of population growth. In Europe, too, a trend towards stricter nutrient emission limits is discernible. Urine source separation would also be beneficial for water pollution control, as the ecotoxicological hazard posed by human medicines could be reduced by an estimated 50 % (cf. Nova 5). In countries with chronic shortages of nutrients for agriculture, wastewater represents a local resource. The nutrients which it contains can best be recovered by at-source measures.

The NoMix technology can turn a wastewater treatment plant from an energy consumer into an energy producer: instead of 11 watt per person being consumed, 2 watt of primary energy per person can be generated, as the energy efficiency of many processes is increased and the energy in wastewater can be better exploited [3]. Thus, the wastewater management sector could contribute to the attainment of the "2000-watt society", the Federal Council's aspiration target of reducing Switzerland's primary energy consumption from 6000 watt to 2000 watt per person. Energy savings could also be realized in fertilizer production, with energy-efficient processing of nitrogen and phosphorus for the agricultural sector [4]. In view of the deteriorating quality of artificial phosphate fertilizers – remaining mineral resources of phosphorus have a high heavy-metal content – it would be worthwhile to recycle relatively pure phosphorus from urine [2]. In the case of nitrogen, the key considerations concern energy and the quality of the fertilizer produced.

As the NoMix technology offers numerous environmental advantages, the decision for or against its adoption is largely influenced by human factors: Is the technology acceptable (Nova 1)? And can it be implemented at low cost, or at least without increasing costs? The costs of the NoMix technology cannot yet be comprehensively estimated. But, according to calculations given in [5], investments of around CHF 1250–2100 per household in this technology would not increase current overall costs in Switzerland. This would, however, require a well-planned system transition, as the additional investments in the NoMix technology

Large sewers and treatment plants to cope with the flood of wastewater: Maybe there's an alternative? (Photo Christian Abegglen)

Potential in every bathroom: Should new housing developments be fitted with the NoMix technology? (Photo Andri Bryner)

would have to be financed by reduced investments in wastewater treatment plants. An increase in the total operating costs of the two systems would have to be excluded.

Nova 7-2: Structuring of the NoMix decision-making process

(Mark Borsuk, Max Maurer, Judit Lienert, Tove A. Larsen)

Nova 7-2 is primarily a methodological project, designed to compare various NoMix technology options in a specific scenario [6]. It is based on a decision analysis considering a wide variety of criteria. This was applied to the Glattpark site (lying north of Zurich), which is currently being developed. Wastewater from this development is to be treated at the Kloten/Opfikon plant, which is already operating at full capacity. This gave rise to the hypothesis that application of the NoMix technology would allow a costly expansion of the treatment plant to be avoided or at least postponed.

Initially, the objectives of the five major stakeholder groups were defined. It was then assessed how far each of the various options fulfilled the different stakeholders' objectives. The main options studied were: (A) NoMix toilets only in the Glattpark development, to level out nitrogen loads at the treatment plant (Nova 3-1); (B) NoMix toilets installed throughout the catchment, with separate treatment of urine; (C) expansion of the treatment plant, without urine source separation. Finally, a ranking of options (from most to least preferred) was prepared for each group of stakeholders. In addition, a sensitivity analysis was performed to investigate the significance of uncertain assumptions for the scenario.

The results show that no single option is equally attractive to all stakeholders. The local authority could make considerable savings if urine was separately collected and treated across the entire catchment. Households, however, will only accept the NoMix technology if a very comfortable NoMix toilet is available and the higher costs are subsidized by the local authority. But for the costs of the NoMix toilet to be sufficiently reduced, mass production would be required – and this is not possible within the planning period envisaged for the Glattpark development. However, the sensitivity analysis also shows that, if greater weight is assigned to environmental questions, the NoMix option rapidly becomes attractive even at a higher price. There are indications, for examle, that the new environmental issue of "micropollutants" could shift priorities in favour of this option.

Conclusions

The NoMix technology is attractive because it has the potential, through a minor intervention, to contribute to environmental protection in an energy-efficient way. Both globally and in Europe, the technology offers advantages over the current situation; waterbodies, in particular, will benefit, as nutrient inputs from wastewater can be substantially reduced. Regions where acute population pressures lead to severe eutrophication of waterbodies would be the areas of choice for initial implementation. In addition, the NoMix technology can provide a valuable local source of fertilizers where nutrients for agriculture are in short supply. Combined with conventional end-of-pipe (sewer and treatment plant) technology for the remaining wastewater, the NoMix concept could well become economically competitive in Europe too, given that, for example, up to CHF 2000 or more would be available for each Swiss household for investments in this technology. The challenge for research, in collaboration with industry, is now to develop the appropriate NoMix technology at this price.


Stakeholders discuss NoMix toilets (Photo Edi Medilanski)

Work package Nova 8

China

Research background

Nova 8 was concerned with the introduction of the NoMix technology in fast-industrialising countries, where conventional end-of-pipe approaches to wastewater treatment are generally preferred at present. Source control measures such as urine separation could offer a good alternative – not least because of the acute demographic pressures faced by these countries and their often limited financial and scarce freshwater resources. In cases where no sewerage system is yet in place, fast-industrialising countries have greater scope for planning than typical European nations.

Kunming, the capital of Yunnan Province in South-West China and sister city of Zurich, was selected as the pilot region for Nova 8. With a population of about 2.4 million, the city lies on Lake Dianchi, a shallow waterbody with excessive phosphorus levels. By 2020, the number of inhabitants is expected to have grown to 4.5 million. Although six modern wastewater treatment plants have been built in recent decades, water quality in Lake Dianchi has not improved.

The projects were financed by the Swiss National Science Foundation (SNF; www.snf.ch) and the Swiss Agency for Development and Cooperation (SDC; www.deza.admin.ch) and carried out under the Swiss National Centre of Competence in Research North-South programme (NCCR North-South; www.nccr-north-south.unibe.ch). The work received strong support from stakeholders in Kunming – an indispensable aid in gaining access to data and other information.

Nova 8-1 Material flow analysis of wastewater

(Dong-Bin Huang, Hans-Peter Bader, Willi Gujer, Ruth Scheidegger, Roland Schertenleib)

In a doctoral thesis, a methodology was developed for material flow analysis of wastewater – including constituents and pollutants – in fast-industrialising countries, tailored to the particular requirements of such regions. The key factors to be considered are the scarcity of data and rapid urban development. In the study, various strategies for wastewater treatment were evaluated on the basis of material flow analysis, including a number of source control measures [1].

As a case study, the wastewater system in Kunming was modelled. The most important finding was that only about 25 % of all urban wastewater is treated at the city's six wastewater treatment plants; the remainder is discharged into the lake untreated. One of the main reasons is that clean water – especially ground and river water – infiltrates the sewers, so that wastewater is diluted in a ratio of at least 1:1. As a result, around 1600 of a total of 1960 tonnes of phosphorus in urban wastewater enters the lake each year. The ambitious goal set by the local authorities, however, is to restore water quality to 1960 levels, which would mean that only some 30 tonnes of phosphorus per year could be discharged into the lake. This assumes, moreover, that similar efforts are undertaken by agriculture and industry [1]. Lake Dianchi is essentially too small and too shallow to absorb the wastewater from such a huge city – quite apart from the fact that it is also exposed to phosphorus inflows from other sources.

The model indicated that even with "perfect" technology – conditions approximated by the infrastructure in Zurich, for example – the targets set for water quality would not be attainable: at least 56 tonnes of phosphorus per year would still be discharged into the lake. The potential contribution of urine source separation was also revealed by the model: if two thirds of all urine was separated and this source control measure was combined with "ideal" wastewater treatment technology, the goal would only be narrowly missed, with phosphorus inflows of 39 tonnes per year [1].

The real challenge now lies in finding a combination of rational measures that is both realistic and will make it possible to achieve the ambitious goals. Clearly, different solutions will be required for urban as opposed to rural regions, and for older parts of downtown Kunming as opposed to new developments where an infrastructure has yet to be established.

Booming city, "blooming" Lake Dianchi: Wastewater from Kunming causes severe eutrophication, with algal blooms (Photo Edi Medilanski)

NoMix technology, made in China: The faeces are collected in a chamber at the back, while the urine flows into a pot (Image Lin Jiang)

Nova 8-2: Introduction of urine source separation

(Edi Medilanski, Liang Chuan, Zhi Guoqiang, Hans-Joachim Mosler, Roland Schertenleib, Tove Larsen)

What solutions to the problems discussed above are preferred by local experts? The situation was first analysed on the ground in order to gain an understanding of decision-making processes and to identify the local actors [2]. Two-hour interviews were then conducted with representatives of 32 different stakeholder groups, so as to determine their attitudes to source control measures in general and to urine source separation in particular [3].

The most important actor – together with the highest-level political bodies and various environmental protection and planning agencies – is the Dianchi Lake Protection Bureau [2]. This authority plays a key role in all decisions concerning the lake. Local experts also mentioned the important role of private real estate companies, which have the ability to promote or reject alternative wastewater management technologies. An important part in decision-making is also played by research institutes, which can carry out pilot projects. As Nova 8-2 showed, successful pilot projects may trigger large-scale initiatives (see below).

Almost all of the local experts have a favourable attitude towards source control measures [3]. Unlike European specialists, however, they tend to approve of such measures for concentrated wastewater streams, such as toilet waste, rather than for "clean" wastewater, such as rain and river water. The respondents were well aware of the problems associated with existing technologies, such as dry toilets. Nonetheless, an optimistic view is taken of technological developments, and such measures are increasingly accepted by society.

Nova 8-2 included a pilot project involving urine-diverting dry toilets in a rural setting [4, 5]. Overall, this project was very successful, prompting plans to install more than 100 000 dry toilets in similar areas.

Conclusions

In fast-growing cities of fast-industrialising countries with significant population pressures and scarce freshwater resources, the limits of end-of-pipe wastewater treatment solutions are increasingly apparent. In Kunming, urine source separation can make an important contribution to resolving the wastewater problem. Different approaches will presumably be required for rural and urban areas. It is clear that, faced with a population explosion, the city of Kunming is pressing ahead with efforts to rehabilitate the lake – an extremely challenging task. At the same time, stakeholders in this highly dynamic city show a marked willingness to accept innovations, and concrete measures can be quickly implemented in rapidly expanding regions of this kind.

The cantonal library BL in Liestal (Photo Steffen Zuleeg)

Work package Nova PP

Pilot projects

Background

Every innovation has to stand the test of real-life conditions, and technologies can only be refined with the aid of practical projects. NoMix pilot projects are particularly challenging, as the toilets have to be tested by users in their bathrooms before the standards of conventional lavatories have been attained ([1]; see also "Practical guide").

Large sanitary technology companies are reluctant to invest in NoMix toilets while the market is still limited ([2]; Nova 2). However, a sizeable market will only arise if large-scale demonstration projects can be carried out, which in turn pose difficulties owing to the deficiencies of NoMix toilets – a catch-22 situation. The only option is to conduct pilot projects – as best one can – using today's technology [1]. We thank all those who participated in pilot projects for their courage in supporting the NoMix venture. Novaquatis learnt a lot from this experience.

Pilot project I: Private apartments

(Coordination: Judit Lienert)

In 2001, four apartments in an urban housing development were fitted with NoMix toilets by Roediger (www.roevac.com), including a tank in the basement, on the initiative of a developer motivated by environmental concerns. The project received financial support from the federal, cantonal and municipal authorities, while scientific management was provided by Novaquatis. The aim was to study the attitudes of domestic users to NoMix toilets (Nova 1) and their functioning under real-life conditions (see "Practical guide"). In addition, data were collected on urine volumes (Nova 3). Initially, communication with the tenants proved to be difficult, but the situation improved when a single person within Novaquatis was responsible for all contacts. In 2003, defective ceramics meant that two toilets had to be replaced – by conventional toilets, at the tenants' request: one child had had problems using the NoMix toilet, and the other household was generally sceptical. The NoMix toilets met with the approval of the other two households. However, in 2005 these also had to be replaced, as a result of defective ceramics and a malfunctioning urine outlet. As this was the only pilot project involving domestic users, the experience gained is extremely valuable for Novaquatis and the sanitary industry (Nova 2). Our feedback to Roediger was used to make improvements, e.g. to the ceramics.

Pilot project II: Eawag office building

(Coordination: Judit Lienert)

At Eawag, the first NoMix toilet (www.wost-man-ecology.se) was installed in 1997 and then removed in 2003 following blockages. In 2000, another two NoMix toilets (www.dubbletten.nu) and three waterfree urinals connected to a tank were installed close to the cafeteria and auditorium. The urine and the installations were used for research purposes (Nova 2 to Nova 5). Social scientific studies revealed that the NoMix toilets were widely accepted (Nova 1). However, many Eawag staff in particular noted that the technology is not yet fully mature. Visitors tended to be less critical. It was essential for the sanitary installations to be well maintained; otherwise, complaints were – legitimately – quickly raised. The new Eawag office building (www.forumchriesbach.eawag.ch), which was opened in 2006, is fitted with the NoMix technology throughout. It can thus be tested on a large scale even after the completion of the Novaquatis project.

Pilot project III: Vocational college

(Claude Lüscher, Maximilian Mayer)

From 2002 to 2004, the University of Applied Sciences Northwestern Switzerland (FHNW) operated three NoMix toilets and six waterless urinals in a vocational college [3]. The main objective was to test various models and to gain experience. Users' attitudes were favourable. In surveys, many respondents indicated that they were prepared to adapt their behaviour when using the NoMix toilet – e.g. by sitting to urinate (Nova 1). The functioning of the NoMix toilets and urinals was generally satisfactory. Certain urinals gave off an unpleasant odour, especially when they were not cleaned in accordance with the manufacturer's instructions; thus, proper maintenance is essential. Low concentrations of

Connection to the future: A plumber installs a NoMix toilet in an apartment (Photo Timur Bürki)

Pointing the way to NoMix: A familiar symbol leading to an as yet unfamiliar innovation at Eawag (Photo Yvonne Lehnhard)

nitrogen and phosphorus were measured in the tank – presumably because the urine was diluted with flushing water. The experience gained was very valuable when it came to designing the tank and pipes for the larger-scale pilot project IV.

Pilot project IV: Basel-Landschaft cantonal library in Liestal

(Coordination: Gerhard Koch)

The first Swiss pilot project involving full implementation of the NoMix technology was launched by the utilities agency of Canton Basel-Landschaft (AIB) at the cantonal library which opened in 2005 ([4]; www.kbbl.ch). The goal is to evaluate alternatives for urban wastewater management and to test the NoMix technology. This is one of the first projects worldwide to use modern urine treatment technology on a pilot-plant scale. Urine from approximately 200 000 visitors per year is stored in a tank and transported by tanker to a treatment plant, which receives financial support from the Swiss Federal Institute of Technology (ETHZ) Novatlantis project (www.novatlantis.ch). Following laboratory tests at Eawag (Nova 4), a combination of electrodialysis and ozonation was selected as the treatment process [5]. This should permit the production of a stable, hygienized fertilizer, free of micropollutants. The product was granted provisional approval (see "Practical guide"), and it was field-tested in 2006 (Nova 6). A research institute was commissioned by Novaquatis to study user attitudes towards the NoMix toilets. The findings among the general public were as positive as those obtained in earlier surveys (Nova 1).

Conclusions

To facilitate development of the NoMix technology, further pilot projects are required. These are complicated, costly – and risky, since any innovation can be torpedoed by adverse experience. In the longer term, therefore, improved NoMix toilets will be needed (Nova 2).

In public buildings, pilot projects can be readily implemented using today's NoMix toilets if the increased maintenance efforts are undertaken by staff. The public is prepared to use hygienic NoMix facilities (Nova 1). In private homes, however, restraint should be exercised; people are not always keen to live with the disadvantages of NoMix toilets in their own bathroom. Pilot projects in households are possible if the residents know what to expect. Ideally, these should be accompanied by social scientific studies to assess the many unresolved research questions [1].

A clearly defined goal and early involvement of all parties will contribute to the success of NoMix pilot projects ([1]; "Practical guide"). This innovation has far-reaching implications for urban wastewater management. NoMix pilot projects should therefore be supported by wastewater authorities and other policymakers at all levels, as well as by private investors. We hope that the experience gained from Novaquatis will encourage other actors to adopt the NoMix technology in spite of the obstacles encountered.

"What do I have to do, Mum?" Children in particular find it difficult to aim correctly (Photo Ruedi Keller)

The right mixture: To clean NoMix toilets without contaminating the urine, one can use a 10 % citric acid solution and a microfibre cloth (Photo Ruedi Keller)

Practical guide

Would a NoMix toilet be a suitable option for me?

(Judit Lienert, Tove A. Larsen)

Fundamental considerations. If you find urine source separation an attractive approach and would like to install NoMix toilets, your intentions are to be applauded! However, in putting your plans into practice, you will need to consider a number of key points, as the technology is still in its infancy. You should have a clear idea of what you are seeking to achieve with NoMix toilets. Does this goal justify the higher costs – and, for example, the significantly greater cleaning efforts required? Urine-diverting toilets do not yet fully meet the standards of today's conventional lavatories.

One of the main problems is the build-up of urine scale – leading inevitably to blockages (Nova 2). For this reason, like waterfree urinals, NoMix toilets need to be well maintained. In addition, many elements of the NoMix system are not yet fully developed or ready for the market; for example, a urine treatment process is only offered by a single company. In Sweden, it is recommended that urine should be stored for six months for hygienization before being used as a fertilizer. In Switzerland, however, urine-based fertilizers require approval and have to fulfil stringent requirements.

Novaquatis has accumulated several years' experience with NoMix pilot projects. This guide provides an overview of the current state of our knowledge and includes references to key sources (for detailed information see [1]). It should enable fundamental aspects to be considered at the planning stage, so that your NoMix project stands the test of everyday life.

Before the start of the project

Objective. The objective of the NoMix pilot project has to be clearly defined in advance. While this sounds trivial, it is crucial to success – the higher-level goals of urine source separation (e.g. reducing nutrient load at wastewater treatment plants, nutrient recycling) are not relevant in an individual project. They are only applicable once a certain critical mass is reached. Realistic objectives may include further development of elements such as urine treatment, or studying the acceptance of NoMix toilets in households.

Early involvement of all stakeholders. Particularly if NoMix toilets are to be installed in private homes, it is essential to involve all parties at a very early stage. Among the important stakeholders are household members, caretakers and property managers, cleaning staff, architects and plumbers, wastewater treatment plant operators, engineers and planners, local officials, authorities, policymakers and scientists. Projects can only succeed if all parties are prepared to accept the drawbacks of the NoMix technology.

Legal aspects, use of urine. As connections to sewers and wastewater treatment plants are mandatory in Switzerland, approval is required for NoMix pilot projects [2–3]. A contract should specify who is to assume the risks (malfunctions, accidents) and who is to bear the costs if installations have to be removed. We recommend the conclusion of written agreements with the main parties (e.g. tenants).

The fate of the urine must be determined at the beginning of the project. Fertilizers require approval, which in Switzerland is granted by the Federal Office for Agriculture [4–5]. In what is currently the only (provisional) Swiss fertilizer licence for urine – from the BL cantonal library – strict quality requirements are specified (Nova PP). Urine can also be used for nutrient peak shaving at wastewater treatment plants (Nova 3) or for development of treatment processes (Nova 4). If a project is designed, for example, to investigate user attitudes in daily life, urine may also be released into the sewers without being further used (Nova 1).

Technological aspects

NoMix toilets and waterfree urinals. Undiluted urine from men can be collected with the aid of waterfree urinals. A wide variety of systems and models are commercially available [6]. In all cases,

Essential maintenance: To prevent blockages, urinal components are exchanged according to manufacturer's recommendations (Photo Ruedi Keller)

Urine on tap: At the withdrawal point, urine collected in Forum Chriesbach can be pumped into a tanker as required (Photo Karin Güdel)

urinals need to be carefully maintained to avoid troublesome odours, unsightly stains and blockages. Good ventilation can help to prevent odour problems.

Two flushing systems are used in NoMix toilets [7]: e.g. in Dubbletten appliances, the urine compartment is flushed separately with a small amount of water (8 ml–2 dl). This saves water – provided that users dispose of urine-soiled paper in a bin, rather than using the full flush for this purpose. Although more recent NoMix toilets are fitted with a conventional dual-flush system (small: 2–3 l, full: 6–7 l), the urine tank receives only a small amount of water (2.5 dl, Gustavsberg) or – thanks to an ingenious closure mechanism – none at all (Roediger). Thus, while these NoMix toilets do not use less water than a modern dual-flush appliance, lightly soiled paper does not have to be disposed of separately.

The disadvantage of the Roediger model is that the urine drain is only opened when the user is seated. With other models, an accurate aim remains sufficient for male users – among whom sitting is unpopular. Here, waterfree urinals may offer an alternative. Women, for their part, are reluctant to sit on public toilets for hygiene-related reasons. Some users find it difficult to adopt the required sitting position. Children in particular have problems targeting the right compartment, which increases the need for cleaning. However, Dubbletten offers a separately available child seat [7].

Cleaning and maintenance. Broad acceptance can only be gained with sound maintenance. Public sanitary facilities have to be cleaned at least daily. If it is necessary to ensure that no water and only harmless chemicals enter the urine tank, cleaning with, for example, a damp microfibre cloth and a 10 % citric acid solution is recommended [1].

One of the main problems affecting NoMix toilets is the build-up of urine scale, which blocks siphons and pipes (Nova 2, [8–9]). To prevent the formation of precipitates, the urine drain can be regularly flushed with acid [1]. Blockages can be removed using a strong acid or caustic soda, or by mechanical means [8–9]. Certain design measures can help to avoid blockages later on: pipes with the steepest possible slope (at least 2–5 %), no tight bends or inaccessible sections, and a large diameter (65–110 mm) (for further information see [1, 6]). In waterfree urinals, precipitates are frequently collected in siphons, which have to be regularly replaced to avoid drainage problems.

Urine storage, transport and treatment. The urine tank should have a capacity appropriate to the requirements of the project, should be water- and odour-tight and resistant to urine and strong acids. It should have an overflow outlet and possibly also include a stirring mechanism, sampling points and a pump [1, 6]. As urine tanks often emit unpleasant odours, good ventilation is extremely important.

For information on urine transport, see Nova 3. A struvite reactor permitting the recovery of phosphorus from urine is available from Huber [10]. All other urine treatment processes are still at the laboratory or pilot stage and await further development (Nova 4). Perhaps this could be an objective of your NoMix project?

Costs. Innovations are always more expensive than tried-and-tested technologies, for which considerable demand – and a large market – already exists. Urine source separation is no exception to this rule. NoMix toilets cost about twice as much as conventional models. Additional costs are associated with urine pipes, tank, transport and treatment. The costs will be further increased if prototypes are required. Accordingly, no information on prices is included here (for an overview, see [6–7]).

Conclusions

Although there are good reasons for installing NoMix toilets, anyone intending to launch a project of this kind should be aware that these are pioneering efforts. Compared with conventional options, you should expect higher costs and other drawbacks with NoMix toilets. We wish you every success with your project. Our team will be glad to offer advice, further information and the detailed article [1]: novaquatis@eawag.ch.

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Cover: The synthesis of Novaquatis is based on many research projects on urine source separation: 1) concerning scaling of urine in pipes (large photo), 2) in private bathrooms (above), 3) in the laboratory (centre) and 4) in pilot projects, for instance in China (below). Photos: Ruedi Keller, Yvonne Lehnhard, Edi Medilanski.

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NoMix

Final Report of the Transdisciplinary Project Novaquatis

Novaquatis – a cross-cutting Eawag project

The transdisciplinary research project Novaquatis is concerned with urine source separation as a new element in wastewater management. The goals are to improve water pollution control by reducing inputs of nutrients and micropollutants, and to close nutrient cycles.

From 2000 to 2006, this cross-cutting project explored the potential of urine source separation – also known as NoMix technology. Novaquatis comprises **nine work packages**, largely organized around the various stages of a nutrient cycle (see Figure on page 2). Participating in the project were researchers from the fields of sociology, economics, natural sciences and engineering. They worked closely together with the sanitary technology industry, local authorities and a fast-industrialising country – China. The main results of the project are presented in this booklet.

While urine accounts for less than 1 % of total wastewater volume, it contains 50–80 % of all the nutrients in wastewater – and these components have to be degraded at wastewater treatment plants Many micropollutants, i. e. residues of pharmaceuticals and hormones from human metabolism, also enter wastewater via urine. Urine source separation could simplify – or remove the need for – nutrient elimination at wastewater treatment plants. Nutrients recovered from urine could be recycled to agriculture, and micropollutants directly removed. The NoMix technology helps to save water and increases the flexibility of the entire wastewater management system. It could thus make a significant contribution to resolving global water pollution control issues.

Eawag is a Swiss-based and internationally linked aquatic research institute committed to an ecological, economical and socially responsible management of water – the primary source of all life. It is part of the ETH domain and carries out research, teaching and consulting. Eawag acts as an important link between science and practical application.