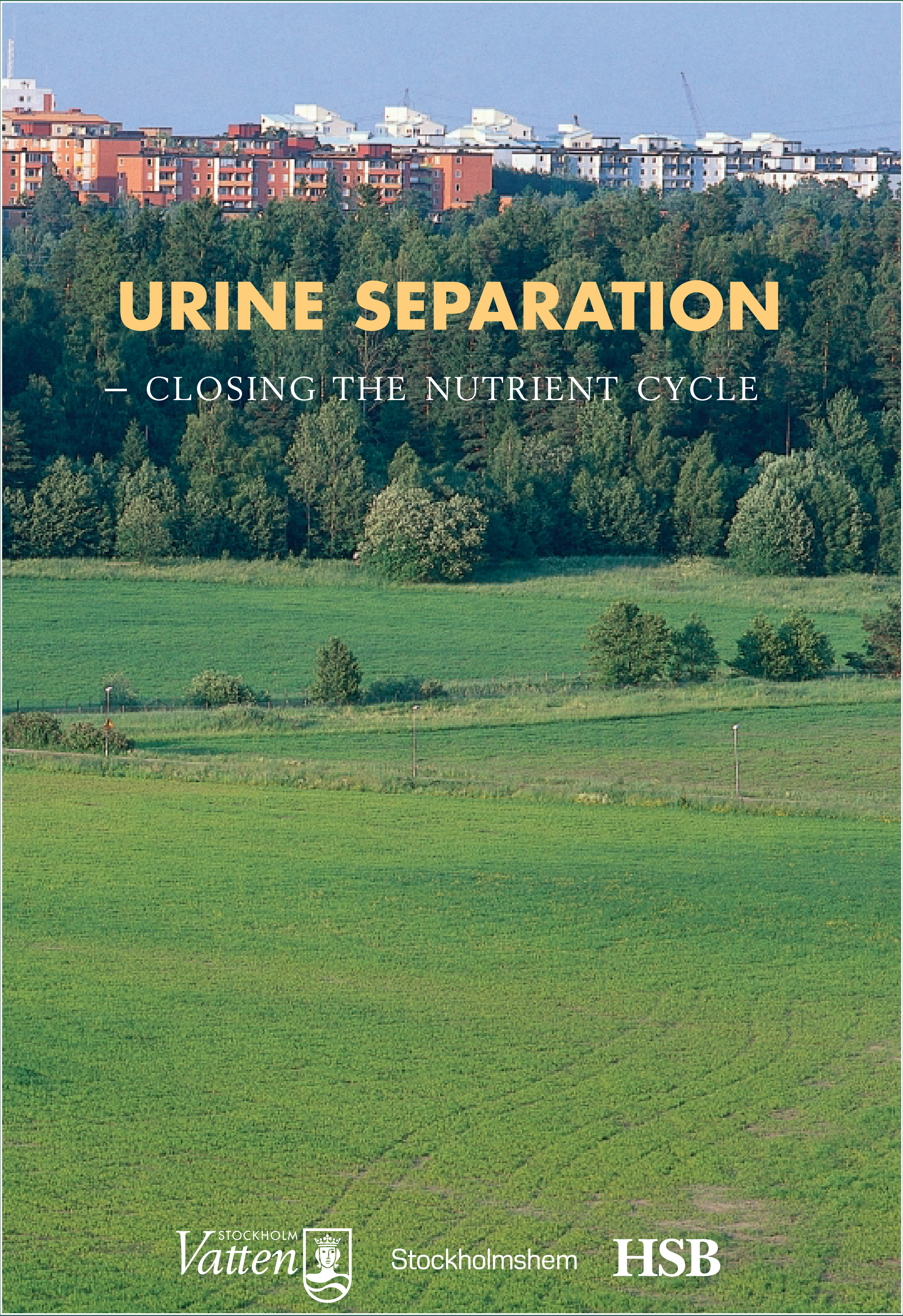

URINE SEPARATION

– CLOSING THE NUTRIENT CYCLE

Stockholm Vatten
Stockholmshem
HSB

This report presents the present state of knowledge about urine-separating toilets and systems for the recirculation of urine as an agricultural fertilizer.

It is aimed at a broad target group of residents, building owners, farmers, politicians, officials and other interested parties.

The results presented here are based on the R&D project Source-Separated Human Urine – A Future Source of Fertilizer for Agriculture in the Stockholm Region? which was conducted by the Stockholm Water Company together with the HSB National Federation and AB Stockholmshem, and the project Recycling source separated human urine, which was funded, inter alia, by the Council for Building Research, the Swedish Farmers Foundation for Agricultural Research, and the Swedish Water and Wastewater Works Association.

The report describes why urine separation is an interesting technology and how a system can be constructed for recirculating urine from residential districts to farmland. It also contains concrete recommendations about planning and management of the various components of the system.

The report also describes the research that has been carried out in this area. It concludes by giving concise answers to frequently asked question about urine separation.

The last few years have witnessed great advances in our knowledge of ecologically sound wastewater systems. We now know that, if the wastewater system is properly designed and constructed, separating urine at source can help to close the nutrient cycle without causing hygiene or odour problems. Urine separation also reduces nutrient emissions and often saves energy and improves natural resource management. There is still a great need for construction and evaluation of new urine separation systems and for detailed studies, inter alia, of organizational and economic matters.

Mats Johansson,
VERNA Ecology

URINE SEPARATION

– CLOSING THE NUTRIENT CYCLE

FINAL REPORT ON THE R&D PROJECT

Source-Separated Human Urine

– A FUTURE SOURCE OF FERTILIZER FOR AGRICULTURE IN THE STOCKHOLM REGION?

The principal author and editor of this report is Mats Johansson, VERNA Ecology. The report is the result of close collaboration with the following co-authors: Håkan Jönsson, Department of Agricultural Engineering, Swedish University of Agricultural Sciences, Caroline Höglund, Swedish Institute for Infectious Disease Control, and Anna Richert Stintzing and Lena Rodhe, Swedish Institute of Agricultural and Environmental Engineering.
The Stockholm Water Company was the initiator and owner of the project.

CONTENTS

The report starts with an introductory section presenting the project and explaining why urine separation is of current interest. This is followed by a description of the various components of the urine separation system from the home to field. Each chapter opens with a fact box, followed by concrete recommendations to various interested parties. In conclusion, there is a presentation of ongoing research. The last chapter gives concise answers to the most frequently asked questions about urine separation. The report concludes with explanations of some of the technical terms used and the addresses of the participants in the project.

Photographs: Anna Richert Stintzing, Lena Rodhe, Lennart Quarnström, VERNA Ecology, Thomas Henriksson Orange AB
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FOREWORD

Our modern wastewater systems have made a vital contribution to health, welfare and an improved environment, but they nevertheless have weaknesses that should be critically examined. Useful substances are not always separated from harmful ones in these systems, and the resulting nutrient-rich sludge contains pollutants.

Thanks to persevering efforts in this field, sewage sludge has gradually become purer, and can safely be used as fertilizer in agriculture. However, in the long term it is important for wastewater treatment plants to be able to supply a pure nutrient fraction.

For a number of years, therefore, the Stockholm Water Company has considered possible alternatives or complementary wastewater treatment solutions. We have, for example, initiated and managed the project **SOURCE-SEPARATED HUMAN URINE – A FUTURE SOURCE OF FERTILIZER FOR AGRICULTURE IN THE STOCKHOLM REGION?**

The present report summarizes the results and the knowledge that have been acquired within the framework of the R&D project, which was conducted together with the HSB National Federation and AB Stockholmshem. Apart from the initiators, the project was funded by Stockholm County Council, the Swedish Environmental Protection Agency and the Council for Building Research, which also supported the preparation of the final report.

The project, which has greatly improved our understanding of this field, was carried out in close liaison with a parallel R&D project, **RECYCLING SOURCE SEPARATED HUMAN URINE**, which was funded by the Council for Building Research, the Swedish Water and Wastewater Association, the Swedish Farmers Foundation for Agricultural Research, the Swedish Environmental Protection Agency and the National Board of Health and Welfare. This collaboration proved very rewarding, and the present report has benefited greatly from it.

The purpose of the report is to present a comprehensible summary of the present state of our knowledge of urine-separating toilets and systems designed to recirculate urine as an agricultural fertilizer. It is directed at a broad target group, and its aim is to inform residents, building owners, consultants, farmers, public officials, politicians at all levels and all other interested parties of all relevant knowledge in this area.

I would like to take this opportunity to thank all those who have taken part in the project in various ways, not least the residents of the Understenshöjden and Palsternackan housing estates, who patiently took part in questionnaires, interviews and assessments.

The wide range of expertise among the members of the project group and their creative collaboration have been a great asset and made for a wonderful working climate. Now that the project is completed, it is no exaggeration to say that it has been very successful and has made a substantial contribution to our understanding of how urine separation systems work.

Gunilla Brattberg
Technical Director, Environment & Development
Stockholm Water Company

URINE SEPARATION
– A UNIQUE RESEARCH PROJECT

In 1995, the Understenshöjden housing estate was built in the Stockholm suburb of Björkhagen. Shortly afterwards, the conversion of the Palsternackan estate in Enskede was completed. Urine-separating toilets were installed in both these estates. The aim in both cases was to try out an ecologically more appropriate toilet and sewage system.

In 1996, when the project started, neither of these housing estates had signed any agreements with farmers for urine delivery. There was a lively debate during this period about the environmental advantages and disadvantages of urine-separating toilets. The debate was characterized by sweeping generalizations, which was partly due to the lack of knowledge about these new wastewater systems.

The Stockholm Water Company then initiated a dialogue with two housing companies, the HSB National Federation and AB Stockholmshem, and the three partners agreed to launch a multi-annual research and development project.

The Stockholm Water Company was the project owner and was responsible for the practical implementation of the project. The leading Swedish researchers and experts on urine separation systems were contacted, and the project was planned.

Purpose and aims

The purpose of the project was to increase the understanding of how a wastewater system based on urine separation works and also to find a sustainable outlet for human urine from residential areas in Stockholm. The objective was to construct a full-scale operational system for the recirculation of source-separated human urine from toilet to field. The system should meet stringent requirements as regards the recirculation of nutrients, hygiene, functional reliability and user-friendliness. A longer-term objective was to learn more about designing ecologically sound wastewater systems for the future and to actively disseminate experiences and research findings.

Summary of project activities

- **1996** **Construction of storage tanks, field trials at Berga, measurement and examination of toilets, hygienic measurements.**
- **1997** **Large-scale application of human urine, field trials at Lake Bornsjön, studies of the hygienic and chemical quality of stored urine.**
- **1998** **Large-scale application of human urine, field trials at Lake Bornsjön, open seminar on the project.**
- **1999** **Field trials at Lake Bornsjön, gas exchange measurements.**
- **2000** **Final report and open seminar.**

What has been achieved during the four years of the project?

The initial research consisted in identifying the priority issues that required solutions. The various subprojects were geared to finding these solutions. The project succeeded in answering most of the questions. A number of new questions arose, and most of these were answered too. Some of the problem areas that were identified at an early stage and studied within the project framework were:

The spread of infection and sanitary issues:

- **Survival of pathogenic microorganisms in urine.**
- **Measurement of the faecal contamination of source separated urine.**

Environmental impact and resource management:

- **Emissions of nutrients and BOD from urine separating sewage systems compared to conventional systems.**
- **Amount of water saved by urine-separating toilets.**
- **Quantities of nitrogen, phosphorus, potassium, sulphur and other plant nutrients that can be recirculated to agriculture as a result of urine separation in a housing estate.**
- **How source-separated human urine can be used as fertilizer.**
- **Energy consumption in urine separation systems compared with conventional systems.**

Technical and social aspects:

- **Size of urine tanks and pipe systems in the residential area.**
- **Practical experience of the function of urine separation systems.**
- **Residents' attitudes to urine-separating toilets.**

Who was responsible for implementation of the project?

The Stockholm Water Company was responsible for the management and administration of the project. A project group consisting of representatives of the project initiators, researchers, farmers and other experts met regularly to discuss the various subprojects. In order to obtain feedback on the progress of the project, a reference group was set up consisting of representatives of the Swedish Environmental Protection Agency, Linköping University and the Council for Building Research.

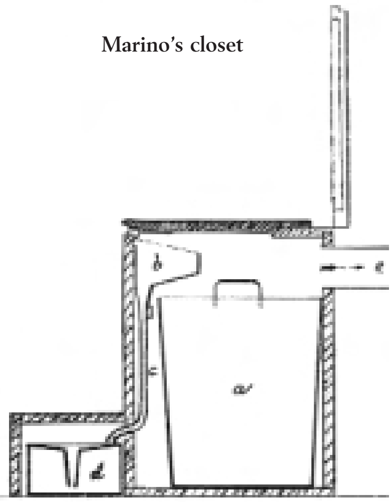
The history of urine separation

Techniques for the separation of urine from the wastewater flow have been applied for many thousands of years in different parts of the world. The reasons for this vary, and the system solutions vary too.

In China, for example, the object has been to reuse the nutrients present in human excreta. There, urine is separated in simple toilets and collected for use as fertilizer locally.

Elsewhere, the main reason for urine separation has been to obtain a dry, manageable and hygienic faecal fraction.

In Yemen, for example, urine is separated in simple toilets and trickles down onto an outside wall where it quickly evaporates in the warm climate.

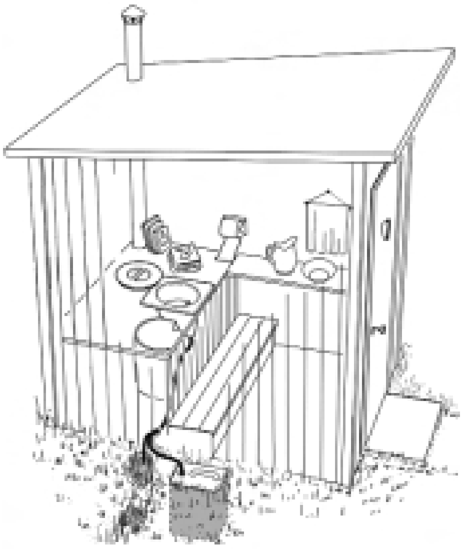


Marino's urine-separating toilet was thought to have solved the hygienic problems of Danish and Swedish cities in the mid-19th Century. Its design was very similar to that of today's urine-separating toilets.

The Swedish invention

In Sweden and Europe the purpose of urine separation has, above all, been to facilitate the treatment of faeces by reducing the amount of liquid in toilet waste.

In the 1970s a number of products and toilet models were developed, including urine-separating insets for holiday houses.



Urine-separating inset for dry closets.

In the early 1990s the first porcelain urine-separating toilets were produced. These were a completely new product. Despite the enthusiastic advocacy of pioneers such as Bibbi Söderberg, who invented the Dubbletten toilet, and Professor Mats Wolgast of Uppsala University, urine separation systems in housing other than holiday and mobile homes was only taken seriously by "alternative" groups with a special interest in the environment. Today's urine-separating toilets are a Swedish invention. To start with, they were used mostly in eco-villages and holiday homes. Nowadays they are also installed in ordinary detached houses, apartment blocks and many schools in different parts of the country.

State of knowledge at the start of the project

In 1996, when the R&D project started, the first urine-separating toilets had been on the market for two years or so and had been installed in some eco-villages.

However, not very much was known about how they worked and they were still mostly sold to holiday home owners, who wanted to lower their water consumption, and to housing estates, as a means of closing the cycle for the nutrients in toilet waste. Their great advantage in this connection is that they make it possible to recirculate nitrogen to farmland, which is still a problem for large-scale conventional wastewater systems.

As more of these toilets were installed in apartment blocks, and not just in holiday homes, politicians and other stakeholders proposed large-scale introduction of urine separation. Urine-separating toilets were discussed as never before and represented a symbolic issue for many ecological housing projects.

Lively discussion and debate

The proposals for large-scale introduction of urine-separating toilets polarized the debate.

The champions of the new toilets claimed that water toilets and the large-scale municipal wastewater treatment systems had had their day and it was now time to introduce more ecologically sustainable systems.

Their opponents argued that the new technology was untried and that it increased transport volumes and involved hygienic risks. Wastewater treatment systems in Sweden were perfectly adequate and environmentally sound, they claimed, since they made it possible to recycle phosphorus in the form of sludge from treatment plants.

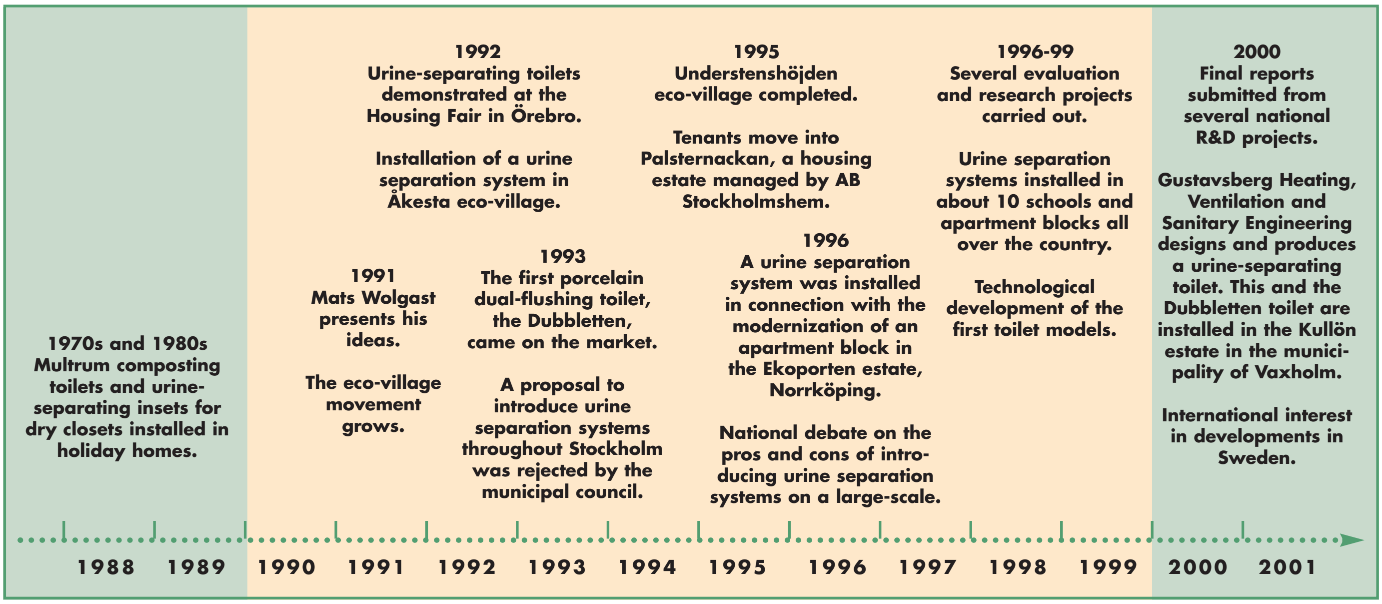


Figure 1. The development of urine separation systems in Sweden in the last 30 years.

Since little was known about the new systems as regards energy consumption, risk of infection, functioning of the toilets, users' attitudes etc., there was no common knowledge base for discussion on the basis of scientific studies. Gradually, the debate became more balanced, and as the knowledge base improved the dialogue became more balanced.

Other research and development projects

When the project started the government had only sponsored a few projects whose aim was to develop and evaluate the new technology. Development was mainly driven by initiatives taken by private housing companies, groups of residents and a few municipally-owned companies and municipal departments, including the Stockholm Water Company. The research projects were funded by several research councils and regional or local financiers.

One of the larger projects carried out was Recycling source separated human urine, which was launched in 1996 and was carried out in parallel with the present project. It was described in a research report summarizing current knowledge about urine-separating toilets and wastewater systems.

The present status of the debate

In recent years urine separation has widely come to be regarded as a complement to conventional systems. There is less discussion of and interest in urine separation at the national level than there was a few years ago.

Urine separation is nevertheless being seriously considered by many municipalities. Interest focuses mainly on the upgrading of individual sewage treatment systems, in particular on simple and cost-effective methods of separating phosphorus and nitrogen.

Urine separation cannot be dismissed as a passing fad, since about 3,000 porcelain urine-separating toilets were sold in Sweden in the latter half of the 1990s. This does not include all the simple urine separation toilets installed in holiday homes.

Our Scandinavian neighbours and the rest of Europe are now showing increasing interest in urine separation. In some cases source separation and urine separation solutions have been designed in order to meet stringent wastewater treatment requirements. One example of this is the Kullön estate in the municipality of Vaxholm, where urine-separating toilets were installed in more than 100 new detached houses in order to meet the municipality's stringent emission standards for nitrogen and phosphorus.

THE ADVANTAGES OF URINE SEPARATION

The purpose of modern urine-separating toilet systems is to separate nutrients such as phosphorus, nitrogen and potassium at source. They can then be used as concentrated fertilizer, since they are free of environmentally harmful substances and undiluted by the wastewater flow.

Most of the nutrients in household wastewater are present in the urine (about 80% of the nitrogen and at least 50% of the phosphorus). Urine only represents just under 1% by volume of the wastewater. The nutrients in urine are therefore quite concentrated and are readily available to plants.

Urine is a pure nutrient solution, which contains very low levels of heavy metals and normally also of pathogenic organisms. Compared with other "alternative" systems, the urine separation technology is comparatively simple and has been adequately tested.

Obviously, urine separation also has some disadvantages. Neither the toilets nor the other components of the system have been on the market for any length of time and the system has had some teething troubles. The main problems have been the toilets themselves and the toilet seals, and the studies and research done in this field have now solved or reduced these problems.

The challenge now is to build large-scale systems with a sustainable organization and economic incentives for recirculating human urine to farmland.

A complementary technology

Urine separation does not solve all wastewater treatment problems. Once the urine has been separated, the faeces and greywater must still be treated.

Urine separation is a complement to both new and existing wastewater systems, and its advantages are that it reduces nutrient discharges and increases the potential for closing nutrient cycles as well as often saving energy.

How urine-separating toilets work

Urine-separating toilets differ from ordinary toilets in that they have two bowls, a front bowl for urine and a rear bowl for faeces and toilet paper. The size and design of the bowls and the flushing technique vary from one model to another. The range of urine-separating toilets is increasing. There are now three different porcelain urine-separating toilets with a dual-flushing system (i.e. for flushing both urine and faeces), and one single-flushing model:

The Dubbletten toilet from BB Innovation & Co AB (both wall-hung and floor models).

The DS toilet, Wost Man Ecology AB's floor model.

Gustavsberg's new wall-hung urine-separating toilet.

A single-flushing model which combines urine separation with dry faeces management.

The two urine-separating toilets studied in this project and the project Recycling source separated human urine: on the left, the Dubbletten from BB Innovation & Co AB and, on the right, the DS toilet from Wost Man Ecology AB (previously WM-Ekologen AB).

From toilet to field

The urine passes through a separate pipe system to a holding tank which is connected to one or more households. The urine is collected and removed by a tank truck or suction truck, which can be driven by the farmer, who uses the urine as fertilizer, or by a contractor.

At present, the estate owner is often responsible for arranging for collection. In future, this should be the responsibility of the municipality as is now the case with sludge collection etc. Such transports consume energy, and it is obviously an advantage if the distance between the property and the place where the fertilizer is applied is short.

Since urine must be stored separately to ensure that it is sanitized before being applied, storage tanks will often be needed near the farmland where the fertilizer will be used. They can also function as a convenient store of fertilizer for the farmer.

Another alternative for house-owners who use about 150 square metres per resident for growing vegetables and fruit is to use the urine as fertilizer in their garden. In that case, they must first obtain a permit from the local environmental health committee and must ensure that the activity does not cause any nuisance to neighbours in the form of smells etc.

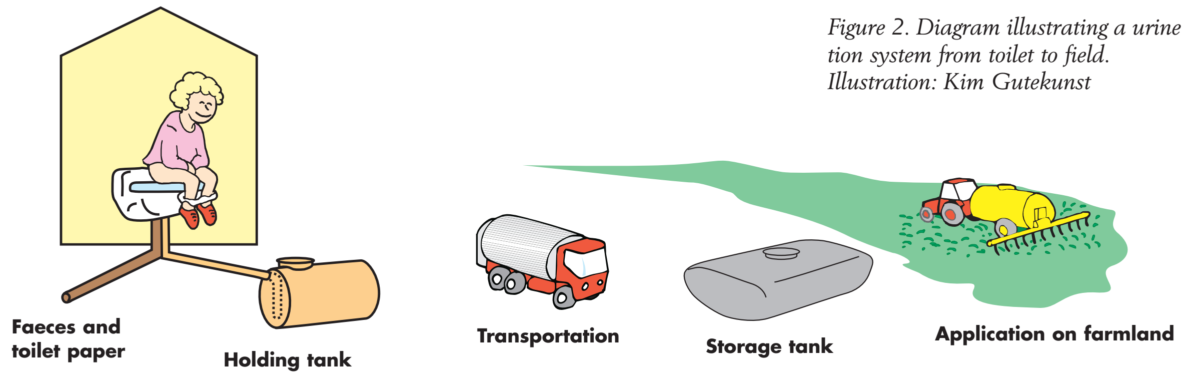


Figure 2. Diagram illustrating a urine separation system from toilet to field. Illustration: Kim Gutekunst

Organization of the system

Several other parties apart from the residents themselves are involved in a urine separation system, e.g. the building owner and the organization or company responsible for the operation and maintenance of the system in the area. In addition, it is often wise to conclude some form of agreement with a contractor or farmer on transportation and disposal of the urine.

Municipal departments have an important coordinating function. They must authorize the installations and wastewater treatment systems, and at the same time give advice in connection with the planning and implementation of the construction project. The municipality's involvement may also be essential when it comes to finding customers for the urine. In the case of small systems, in particular, property owners often need to be supported by a stronger party.

Phosphorus, organic material and nitrogen cause problems in seas, lakes and streams…

… but are valuable to farmers.

Household wastewater is a resource

The wastewater from households contains urine, faeces and greywater, as well as flushwater, toilet paper and other waste that enters the sewerage system. Wastewater has for a long time been regarded as a problem as wastewater involves hygienic hazards, as well as containing eutrophying substances in the form of phosphorus, organic matter and nitrogen.

These substances cause problems in seas, lakes and streams, although they are valuable to farmers.

The nitrogen (N), phosphorus (P) and potassium (K) in wastewater can be utilized instead of artificial fertilizer and the organic material increases the humus content of arable land.

Recirculating nutrients from wastewater as fertilizer reduces the need of industrially produced fertilizer and also reduces discharges of nutrient-rich water from treatment plants into watercourses.

Separating urine

Most of the nutrients that are essential in agriculture (N, P, K) occur in urine. Faeces contain smaller amounts of these substances, while the quantities in greywater are insignificant (figure 3).

Separating urine, which only accounts for about 1% of the total wastewater flow, and using it as fertilizer makes it possible to utilize most of the nutrient content of wastewater. If faecal material is separated too, only small amounts of nutrients remain in the greywater.

It must be borne in mind that greywater represents by far the greatest volume of wastewater and must still be treated. Consequently, urine separation cannot replace other treatment methods but is a complement that helps to recycle a larger proportion of the nutrients in wastewater.

Essential requirements for the recirculation of urine

When closing nutrient cycles, care must be taken not to establish a "cycle" of infectious matter, which will increase hygienic risks, and recirculate an inferior nutrient fraction (due to the presence of environmentally harmful substances and undesired products).

Neither residents or farmers will accept exposure to increased hygienic hazards, and farmers are obviously not interested in fertilizer with low nutrient value or high levels of environmentally harmful substances.

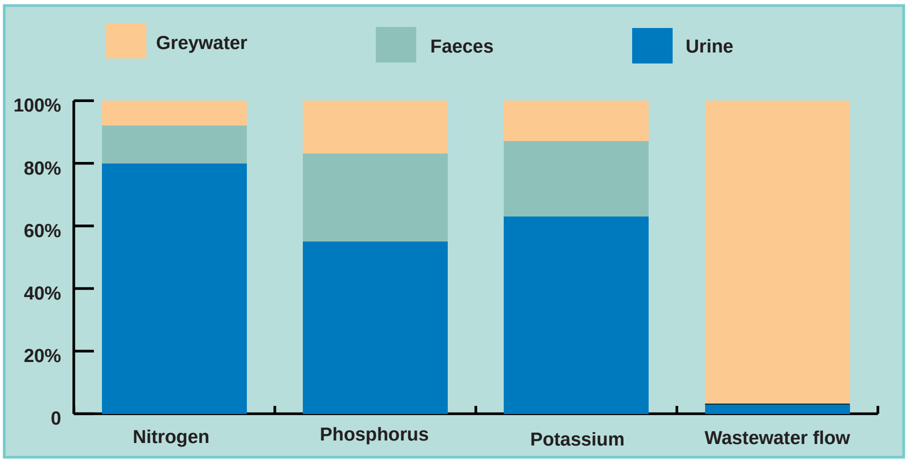


Figure 3. The contribution of urine, faeces and greywater to the nitrogen, phosphorus and potassium content in wastewater and to the total wastewater flow.

THE UNDERSTENSHÖJDEN PROJECT

– LOCAL WASTEWATER TREATMENT IN AN URBAN AREA

The Understenshöjden eco-village is situated in the suburb of Björkhagen, a few kilometres south of central Stockholm. The 160 residents are members of a tenant-owner association which includes all 44 apartments.

The estate, which was ready for occupation in 1995, meets high ecological standards with regard to waste management, construction materials, energy systems and the outdoor environment. Urine-separating toilets and a small treatment plant are important components of the local sewerage system.

The toilets are wall-hung Dubbletten models. The urine passes through a copper toilet seal (many of the seals were subsequently replaced by plastic seals) to a system of welded polyethylene pipes with a diameter of 75 or 110 mm. The urine is collected in two series-connected tanks with a capacity of 40 m^3 each. When the first tank is full, the urine mixture overflows into the other one.

About once a year, the urine that has accumulated in the holding tanks is transported to storage tanks at Lake Bornsjön in Salem. The remaining toilet waste and greywater is treated in a local biological treatment plant, after which it undergoes further treatment in a system of ponds and ditches.

Urine separation and local treatment close to the municipal wastewater system

In Understenshöjden the residents themselves made all the technological choices and decided on system solutions. The aim was to design a waterborne wastewater system that would be an alternative to the conventional treatment plants.

The residents wanted a local wastewater treatment system without chemical precipitation, and this was why they chose a system with urine separation, a local treatment plant and subsequent treatment in ponds and ditches. This alternative was adopted despite the option of connecting up to the nearby municipal wastewater system.

The current situation in Understenshöjden

Since the residents moved in, all the urine has been used as fertilizer for cereal crops. However, the Environment and Health Protection Administration has not granted permission to release the wastewater treated in the local plant into the system of ponds and ditches. At present, therefore, the water is pumped into the municipal wastewater system. The reason for this is that the treated water does not meet the limit value for phosphorus (0.5 mg per litre). It does, however, meet both the hygienic requirements and the BOD requirement of 15 mg per litre.

The residents are currently discussing the future of the local treatment plant. They have, however, decided to keep their urine-separating toilets, which they are satisfied with.

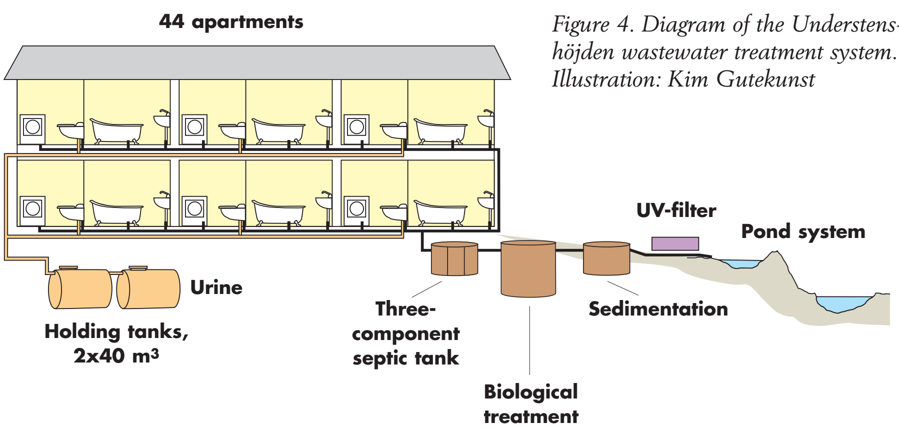


Figure 4. Diagram of the Understenshöjden wastewater treatment system. Illustration: Kim Gutekunst

THE PALSTERNACKAN PROJECT
– ECOLOGICAL CONVERSION OF APARTMENT BLOCKS

The Palsternackan Housing Estate is situated in Enskede a few kilometres south of central Stockholm. The 51 rented apartments, with about 160 residents, are managed by AB Stockholmshem.

The estate previously consisted of apartments for the elderly. In connection with a renovation in 1995 priority was given to environmentally sound construction materials, greenhouses for the residents and a sewerage system based on urine separation. The residents moved in in the winter of 1995-96. Prospective tenants were required to sign an "environmental contract", in which they promised to comply with certain rules of environmental behaviour.

The urine-separating toilets are Dubbletten models. The seal for the urine bowl is of copper, and the pipe system consists of polyethylene pipes with diameters ranging from 50 to 110 mm. The pipes are laid in a conduit system and the urine is collected in three subsystems of roughly equal size, each with a tank of 30 m^3.

The tanks are emptied about once a year and the urine transported to storage tanks at Lake Bornsjön. The remaining wastewater (faeces, flushwater and greywater) enters the Stockholm wastewater system.

Complement to the conventional system

AB Stockholmshem chose urine-separating toilets because they had no experience of ecological wastewater systems and had decided, in line with the environmental profile adopted for the project, to try a new wastewater management solution. An important factor was the desire to try out urine-separating toilets in apartments for "ordinary" tenants who had not chosen their toilets themselves.

The current situation in the Palsternackan estate

Since 1996, all the urine collected has been transported to the farm at Lake Bornsjön. In the spring of 2000, the tenants took steps to set up a tenant-owner association with a view to managing the estate themselves.

No decision has been taken yet, but if the tenants assume ownership of the estate there is no guarantee that they will agree to bear the cost of collecting and transporting the urine in future.

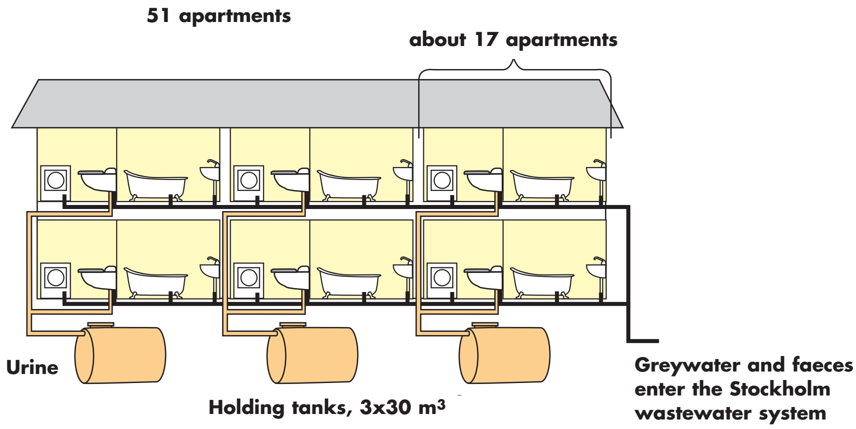


Figure 5. Diagram of the Palsternackan wastewater treatment system. Illustration: Kim Gutekunst

LAKE BORNSJÖN

– A NEW FACILITY FOR THE STORAGE OF HUMAN URINE

In 1900, the City of Stockholm bought all the land around Lake Bornsjön in Salem municipality with a view to securing the future drinking water supply for the population of Stockholm.

Today, Lake Bornsjön is the Stockholm Water Company's reserve water catchment. The Company's goal is to secure the future of Lake Bornsjön as a water catchment and preserve and develop the natural and cultural assets of the area. The water in Lake Bornsjön has been of relatively stable quality over the years, although the input of phosphorus, in particular, is too high.

All activities such as forestry, agriculture, building management, conservation of nature and the cultural heritage are subject to water pollution control. There are sampling programmes for all the streams that run into the lake and the Swedish University of Agricultural Sciences is conducting long-term measurements of runoff from the farmland where human urine is applied.

Storage of human urine at Lake Bornsjön, about 30 km southwest of central Stockholm.

Description of the storage tanks

Thanks to the interest in developing urine separation systems and the availability of cultivated land and cooperative farmers, the Stockholm Water Company was able to build a storage facility in the Lake Bornsjön area, which met the requirement for cheap storage and efficiency in environmental terms.

The best solution was to use "balloon tanks" made out of rubber, which are airtight, require little construction work, are reasonably priced and minimize nitrogen losses during storage. If necessary, they can also be moved.

In the spring of 1996 three tanks with a capacity of 150 m^3 each were installed. Since it was impossible to make an accurate estimate of the volume of urine that would be produced in the Understenshöjden and Palsternackan estates, it was considered better to err on the safe side.

It was decided to set up three separate tanks, rather than one or two larger ones, so as to allow separate storage of sanitized and non-sanitized urine from the respective estates. The first deliveries of urine arrived at Lake Bornsjön in the spring of 1996. There have been no problems with the tanks to date. A large number of study visits have been made to Lake Bornsjön, both by Swedish and foreign groups, which indicates the importance of examples of excellence when it comes to system solutions.

Crop growing

Henrik Pettersson, the farmer at Ladvik Farm, has played an active part in the project. He leases the land where the urine fertilizer is applied from the Stockholm Water Company.

Ever since the start of the project, the field where the urine is applied has been used to grow spring barley for forage. The siting of the storage tanks near the fields is practical from the farmer's point of view, since they are readily accessible and make it possible to apply the urine directly by means of a feeder hose.

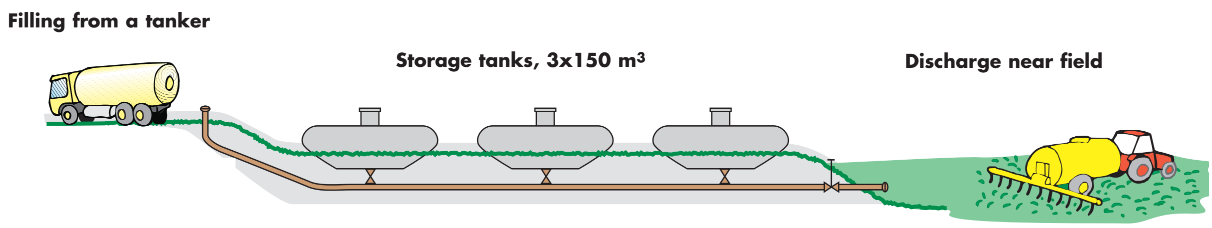


Figure 6. Diagram of the storage facility for human urine at Lake Bornsjön.
Illustration: Kim Gutekunst

URINE SEPARATION
– FROM TOILET TO FIELD

The following section presents the design and construction of urine-separating systems and the research that has been undertaken within the project framework. The information is divided into four parts:

- **The housing estate**
- **Residents' attitudes**
- **Transportation and storage**
- **Crop growing**

Each section starts with a summary of the present state of knowledge followed by advice to various stakeholders and an account of the research that has been done.

Spreading of urine at Lake Bornsjön.

THE HOUSING ESTATE

Urine separation works

Urine-separating toilets have been in operation and have worked well both in apartment blocks and in detached houses for more than five years.

We know today that most of the urine produced in a housing estate can be collected and diverted via pipes to a tank. If they are properly designed, such systems can collect a concentrated urine and water mixture without loss of nutrients and without causing any odour or hygiene problems.

Lessons learned from the first urine separation systems

The urine-separating toilet systems have had some teething troubles:

- Odour problems due to poor design and installations that are not watertight. In projects where the urine-separating toilets are properly connected to the pipe system these problems have not occurred.

- One major problem has been the occurrence of stoppages in the toilet seals, which has caused an odour nuisance, thus necessitating extra work for the residents or the housing managers. We now know that it is easy to clear these stoppages.

- To start with, there were no capacity specifications for the pipe systems and holding tanks, and therefore the pipes and tanks were not adequately designed. We can now make appropriate recommendations for the design and dimensions of the system as a whole.

- Groundwater leaked into the piping systems and holding tanks and soon filled them completely. We have now realized that the pipes must be completely watertight.

Concise facts – Urine separation in residential areas

- **Allow sufficient capacity for 1.5-2.5 litres of urine solution per resident per day, depending on the toilet model.**
- **There is a direct correlation between residents' motivation and the quantity of urine collected.**
- **Stoppages occur in the toilet seals, but it is easy to clear them.**
- **Nitrogen losses are very small in the housing estate itself.**
- **It is easy to prevent odours and ammonia losses.**

Instructions to residents and housing managers/caretakers

Do not clean both the toilet bowls with the same materials (or if you do, make sure to clean the urine bowl first). The ceramic stopper in the Dubbletten should be removed, since it is probably the cause of accumulations of hair etc., which in turn causes stoppages.

If the water flow in the urine bowl appears to be lower than usual, use a mechanical snake, or use a solution of sodium hydroxide (caustic soda dissolved in water) and leave overnight. Then flush the toilet seal with about two litres of water at high pressure.

Use ecolabelled cleaning products.

Make sure to use as little water as possible for flushing the urine. Too much water dilutes the urine and reduces its value as a fertilizer and increases the transport volume.

If you want to save water, either place toilet paper in the rear bowl without flushing or place it in a separate waste basket.

Instructions to building owners and contractors

Make sure that the residents are informed of the reasons for using urine-separating toilets.

The quantity and quality of the urine that is separated depends very much on the users' motivation; the greater the users' awareness and motivation, the higher the percentage of urine separated.

Insist that the toilets supplied by the manufacturer work properly and are of high quality.

Demand detailed and accurate installation instructions from the toilet suppliers.

Proposals for development

Many improvements in the existing toilet models have been suggested:

- In order to increase the amount of urine that is collected and to ensure a cooperative attitude among residents, the toilets must be designed in such a way that men can stand up when urinating.

- The toilet must be designed in such a way that it is easy to clean the seal and replace it, and that the risk of faeces entering the urine bowl is reduced.

- The flushwater (which should be minimized) should flush the whole of the urine bowl and the partition between the two bowls.

- The toilet must also be adjusted to standard measurements and supplied with the necessary connection parts and appropriate instructions for installation, use and maintenance.

- Finally, on account of the risk of precipitation and contamination, no metals should be used in pipe systems designed for source-separated human urine.

The function of the toilet

The urine-separating toilets that have been evaluated were the first ever in serial production and may almost be called prototypes. Consequently, many small defects have been rectified in later models. As mentioned above, the greatest problems have been stoppages in toilet seals and odour.

Urine-separating toilets look different, which is appreciated by some users but not by others. One of the most controversial questions has been whether or not men must sit down when urinating. This is not absolutely essential, but separation is more efficient if male users do sit down, apart from which less cleaning is needed.

Normal stoppages blocking the toilet seal can be cleared with a mechanical snake. Stoppages due to chemical precipitation must be dissolved with concentrated caustic soda.

Stoppages in the toilet seal

One of the problems that was noticed at an early stage in the studies of the Understenshöjden and Palsternackan estates was that stoppages occurred in virtually all the toilets after a while.

The majority of these (76%) were normal stoppages caused by hair and material from bottle or toilet brushes, combined with crystalline precipitations, that accumulated in the toilet seals. Such stoppages can be cleared by using an ordinary mechanical snake.

A smaller number (24%) were caused by crystalline precipitations on the pipe walls. Later studies have shown that such stoppages can easily be cleared by pouring a concentrated solution of caustic soda into the seal, letting it stand for at least three hours and then flushing.

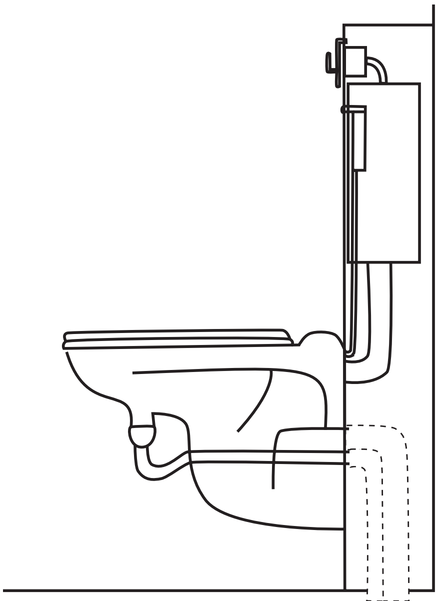


Figure 7. Side view of the wall-hung Dubbletten model with a toilet seal for the urine pipe.

Quantity and composition of the urine mixture

The capacity of the urine separation system is determined by the quantity of the urine mixture that is collected. The time spent at home by residents obviously decides the quantity of urine and nutrients that is collected. Surveys indicate that residents spend an average of about 15 hours a day at home.

To ensure that the quantity of urine that is collected is as high as possible, it is important that residents know how to use the toilets properly and that they are satisfied with the system. If not, there is a greater risk that they will not bother to separate the urine and that the separation system eventually will be replaced by a conventional system.

Studies have shown that, where the Dubbletten is installed, the capacity of the system should be sufficient to collect about 1.5 litres of urine mixture per person per day.

Other project studies show that the capacity of systems based on the Wost Man Ecology DS should be geared to a quantity of about 2.5 litres per person per day. These are the only toilet models that we have studied.

It is important to use as little water as possible for flushing the toilet, since

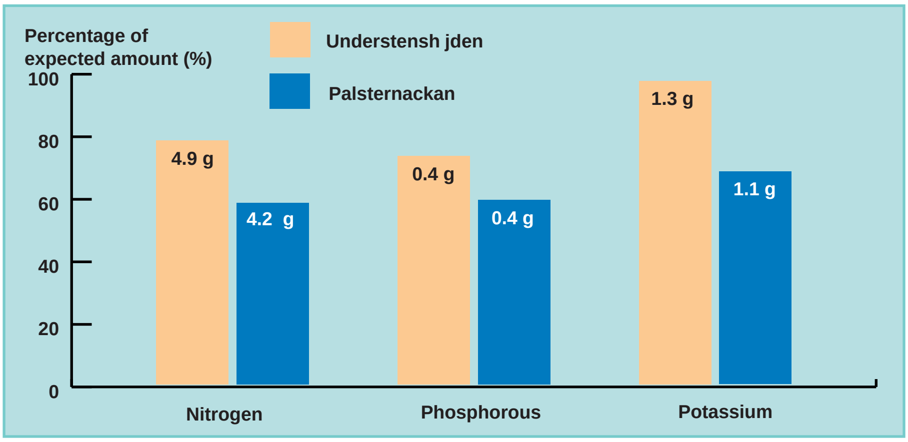


Figure 8. Percentage of expected amounts of nutrients collected in urine from Understenshöjden and Palsternackan. The bars show the amount of nutrients in grams per person per day in respective area.

dilution increases the volumes held in the tanks, the need of transport and the work of spreading the fertilizer. Besides, the quality of the fertilizer is obviously lower if it is diluted.

The amount of urine that was actually collected in the housing estates that were studied was less than might have been expected. Between 58% and 95% of the theoretical potential quantity of nutrients was present in the urine tanks. This means that the rate of error as regards separation was about 20% even among the most motivated residents (Understenshöjden). Among residents with no particular motivation (Palsternackan) the figure was about 40%. The higher the residents' motivation, the greater the amounts of nutrient collected.

Research

Several studies and measurements were undertaken within the project framework. For example, automatic flushing counters were installed in the apartments in Understenshöjden and Palsternackan. These count the number of times the toilet is flushed, the amount of water used and other parameters.

In addition, the quantity and composition of the urine from both estates were measured. This made it possible to calculate the quantity of the urine mixture collected per person per day, and this was the basis of the capacity specifications. The chemical composition of the mixture was measured as a basis for a comparison of the amount of nutrients with the estimated potential assuming that all the urine had been separated and collected.

A detailed questionnaire survey was also carried out in all households in both estates, as well as in three other estates where urine separation systems are installed. In responding to this questionnaire, the residents described how much time they spent at home, how they looked after their toilets and whether or not stoppages had occurred in their toilet seals. As a result of the questionnaire survey, 17 seals where stoppages had occurred or the flow had been greatly reduced were examined.

On the basis of the findings of the questionnaire survey and house calls, laboratory investigations were undertaken to find out whether the material in the seals or the water flow were significant factors in causing the stoppages. It was found that a deposit built up faster in seals made of copper than in plastic seals. It was also found that flushing with a large quantity of water for a short time and using acidified flushing water reduced the buildup of deposit.

Neither of these methods actually prevented stoppages, but helped to delay them. The greatest effect was achieved by using acid flushing water (pH 1). However, this method is not a feasible alternative, since both flushwater and the urine mixture are hazardous to health at such a low pH level.

A high flow rate and a larger amount of flushing water (0.3 litres per flush) slowed the buildup of deposit by 75% compared with seals flushed with the normal amount of water (0.1 litres). But this method cannot be recommended either, since it dilutes the mixture.

Pipe systems

Water leaked into the pipes and tanks in several places, which made it necessary to empty and transport the tanks more frequently and made the fertilizer less attractive. Moreover, it was often not possible to carry out checks and service and flush the pipes. These procedures are essential, since sludge is formed in the pipes. The recommendations given below should be followed in order to avoid these problems.

Pipe systems and the collection of urine

The urine and flushwater mixture passes through a separate pipe system to a holding tank. Since our studies show that metals used in toilet seals and pipes react, in particular, with the phosphates in the urine, no metals should be used for the pipes and installations.

In large-scale urine separation systems the urine mixture is collected from all the households and diverted into one or more tanks. The number of tanks in a housing estate and the way they are connected varies. Either all the urine collected in the estate is diverted to one or more central tanks, or it is collected in smaller local tanks with shorter pipe systems. The latter system reduces the risk of groundwater leaking into the pipes and of the urine solution leaking out.

Two or more parallel connected tanks can be used both as holding and storage tanks that are alternately filled up and used to store the solution.

Research

About 70 metres of the urine pipes in Understenshöjden were video-filmed, and in Palsternackan they were inspected through apertures in the pipes to check for the risk of clogging and stoppages.

These inspections showed that where the pipes were laid at a sufficient inclination (at least 1%) and the diameter was large (110 mm) the amount of sludge that had formed on the bottom was negligible after 2-2.5 years of operation. There were no indications of future problems. Where, however, the inclination was less than 1%, or there were backfalls, or the inclination was sufficient but the diameter of the pipes too small (50 mm), heavy, viscous sludge formed on the bottom, and this was considered likely to present future problems for the flow. However, the sludge did not adhere to the pipes and could easily be flushed out with a garden or high-pressure hose. Following these studies, occasional stoppages have occurred in one pipe in one of the 20 larger urine separation systems in the country, but these have not been examined.

Recommendations to building owners, consultants and contractors

The planning phase:

Flow capacity: about 1.5 urine solution per person per day for the Dubbletten model and about 2.5 litres for the Wost Man Ecology DS model.

The urine pipes must not be ventilated (due to the risk of odour and ammonia losses) and must be made completely watertight by means of welded joints or equivalent.

The pipes should be laid at an inclination of at least 1% and should be at least 75 mm (preferably 110 mm) in diameter. Backfalls in the pipes can cause stoppages.

The pipes and tanks should not contain metals or harmful substances that may be released or react with the urine.

The pipe system should be designed in such a way as to facilitate inspection and cleaning.

Allow for the cost of recirculating the urine to farmland in your budget.

The operation phase:

The pipes can be flushed as necessary at normal water pressure or by jet cleaning.

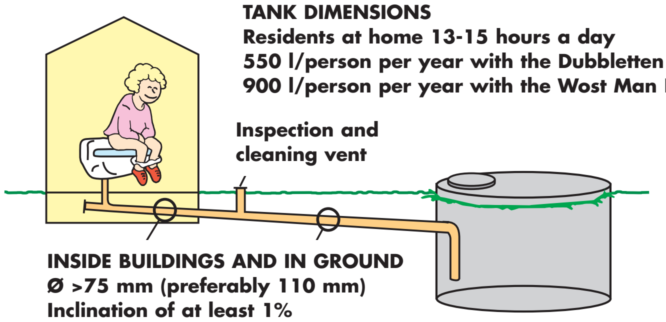


Figure 9. Recommendations concerning the dimensions and inclination of pipes and the capacity of holding tanks for urine separation systems. Illustration: Kim Gutekunst

Physical properties and biological activity

Studies were made of the distribution of particle sizes in the sludge that forms in the pipes. Moreover, a rise in the pH level from 7 to 9 was observed during the transport of the urine solution to the holding tank.

The respiration in the sludge that formed in the pipes was analysed. The analysis showed that organic material in the sludge is converted into carbon dioxide, which indicates bacterial activity and possibly growth in the pipe system. The latter applies also to certain bacteria that are used as indicators of the presence of faecal material.

Holding tanks

The tanks are of fibreglass plastic and are standard products used in other construction works. The technical components are not new, although they have not previously been used for the purposes of holding separated urine. The nitrogen losses in the housing estates were less than 1% in all the conditions that were studied.

For optimum results in environmental and hygienic terms, as well as from the point of view of operation, the recommendations given below should be followed in connection with the collection and storage of urine.

Recommendations to building owners, consultants and contractors

The planning phase

The holding tanks and their connections must be completely impervious to the surrounding water. They must be designed so that the tank is filled from the bottom (the incoming pipe must be bent towards the bottom of the tank); the pressure should be equalized, but the tanks must not be ventilated.

Attention must be paid to the lifting force of groundwater where the level is high. Consider the possibility of using a suction well and a holding tank located at the surface or above ground.

The manhole of the holding tank should be located close to the incoming pipe, so that it is easy to inspect the pipe. The tank cover should be secured in such a way as to minimize the risk of children falling into the tank.

If several tanks are installed, they should be placed in parallel, and not serially connected, so that they can be filled alternately.

The operation phase and stoppages

A thin layer is formed of particulate-rich bottom sludge with high levels of nitrogen, phosphorus, calcium, magnesium etc., but this is not likely to affect the emptying of the tanks.

Great care should be taken and the regulations issued by the National Board of Occupational Safety and Health should be followed if it is necessary to go down into the urine tank, and this task should never be undertaken by one person alone.

Design and location of holding tanks

It is possible to store all the urine produced in the housing estate until it is collected, but in that case the tanks will have to be larger than if the urine is stored near the fields where it is to be applied. In any case, the tanks should be within convenient reach of tank trucks and any other equipment used for collection.

The manhole of the holding tank should be located close to the incoming urine pipe, so that it is easy to inspect the pipe. Great care should be taken if it is necessary to go down into the urine tank, and the regulations issued by the National Board of Occupational Safety and Health must be complied with.

The tanks should be filled from the bottom, which will be the case if the incoming pipe is bent towards the bottom of the tank (see figure 9, p. 17). The holding tanks and their connections, which are often located deep in the ground, must be designed in such a way as to be completely impervious to surrounding water and resistant to the lifting forces of the water.

There is no experience in Sweden of pumping human urine into pipe systems, but pumping urine to a holding tank above ground should not present any technical problems.

Research

The holding tanks in several estates were inspected in connection with measurements of the flow and the content of the tanks. This yielded a great deal of information about both the design and the function of the tanks. Careful measurements of the various strata of the urine in the tanks also provided data about the distribution and conversion of nutrients in the tanks. Gas exchange measurements were made in order to determine how much nitrogen was lost from the holding tanks in the form of ammonia. These established the number of gas exchanges per day in the tanks and therefore made it possible to calculate the actual losses of nitrogen during holding and storage.

RESIDENTS' ATTITUDES

If the residents are motivated and well-informed, this has a significant effect on the functioning of the system. The questionnaire survey of the residents' expectations with respect to urine-separating toilets was carried out among households in five housing estates altogether. At the time of the questionnaire the residents had used the urine-separating toilets for between six months and three years.

The most important findings of the questionnaire survey

- Urine-separating toilets do not smell noticeably more than other toilets, although several households had an odour problem at the start. This was mainly because of inferior or faulty installation.

- Urine-separating toilets are not more difficult to keep clean than conventional toilets. Compared with a conventional toilet, respondents found that the Dubbletten toilet required more work, while the Wost Man Ecology DS toilet was somewhat easier to keep clean. There were complaints that the Dubbletten toilet did not flush the bowl clean and that it splashed. The toilets were examined and the flushing function improved.

- The difference between the various estates as regards the concentration of nutrients in the urine was probably due to the fact that the Palsternackan residents were not as careful to ensure proper separation of the urine as those in Understenshöjden. Some of the Palsternackan residents stopped using the front bowl of the toilet (the urine bowl). This may have been because men prefer to urinate in a standing position, and in that case it is easier to use the rear bowl.

Concise facts – what do the residents think?

- **Regular information to the residents increases their motivation for using the toilet as intended.**
- **The odour problems in connection with urine-separating toilets do not appear to be greater than with other toilets.**
- **When the system works properly the residents accept it.**

Research

The surveys carried out in Understenshöjden, Palsternackan and other housing estates took the form of a questionnaire sent to all households. The questions related both to general data about the households and particulars of how they looked after their toilets and what they thought of them.

Residents are willing to try the new toilets for environmental reasons

An in-depth study of the behaviour of the residents in the Palsternackan estate was carried out in 1997 by a research group from Chalmers University of Technology and Gothenburg University. The purpose of the study was to establish how information about the functioning of the sewerage system affected the residents' attitude to their urine-separating toilets.

The study showed that both the initiators of the project and the residents were curious about the new toilets. AB Stockholmshem is keen to be at the forefront of developments in environmental technology and is not afraid of breaking new ground. The users stated that they were happy to be able to do their share to improve the environment and were proud to be a part of the project. Nevertheless, some of them questioned whether the toilets really benefited the environment. The fact that it was sometimes necessary to flush the toilet more than once and uncertainty about the hygienic quality of the urine worried some respondents. If a satisfactory solution is found to these problems, both the housing company and the users are in favour of urine separation. Few residents had any qualms about eating food fertilized with human urine.

TRANSPORTATION AND STORAGE

When the project started there was no experience of full-scale systems for the recirculation of urine to agricultural land. Where this had been tried, the volumes were small and were collected by local farmers from the housing estate for application directly in the field. In some housing estates extra storage tanks were installed near the buildings, while in others sufficient capacity was found near the fields where it was to be applied.

During the four years that the project has been in progress a system for transportation and storage has been built up, tested and found to work well.

Concise facts – transportation and storage

- **Transport systems and technology for the storage of urine are available on the market.**
- **Nitrogen losses during transportation and storage can be kept very low if the urine is stored in non-ventilated tanks.**
- **A high temperature, low dilution and high pH levels promote the sanitization of the urine mixture.**
- **Storage recommendations have been prepared for human urine (see p. 29).**

Advice to housing managers

Conclude long-term agreements with farmers and/or contractors.

Demand that the tank trucks are cleaned prior to transport, since the urine is very pure and even small quantities of pollutants impair its quality.

Ensure that the tank connections are within easy reach of the tank truck.

If permanent suction pipes are installed, they should be of large diameter (preferably 150 mm) in order to minimize loading times.

Recommendations for the management of human urine

The urine mixture should be stored in order to achieve adequate hygienic quality. If it is stored for six months without the addition of any new urine, sanitation is sufficient for the urine to be used on any type of crop. The storage time can be shortened, depending on the crop in which the fertilizer is to be used and how the urine is stored. Detailed storage recommendations will be found in the chapter Hygiene and protection against infection.

Measures should always be taken to minimize the risk of infection.

The urine solution should be stirred when a representative sample of the urine tank is to be taken. If this is not possible, it is recommended that samples be taken from the middle of the tank.

Locate the storage tanks close to the fields where the urine is to be spread and make sure that it is easy to collect and deliver the urine.

Make arrangements for the transportation and utilization of the urine, preferably long-term agreements.

Transportation from holding tanks to the storage facility on the Stockholm Water Company's land at Lake Bornsjön

When the holding tanks in the housing estates were full, or six months before the urine was to be applied, a contractor (RagnSells Agro) received an order to empty the tanks. The urine was pumped into tank trucks and trailers and then transported to Lake Bornsjön and emptied into the storage tanks by gravity.

The total volume of urine transported to Lake Bornsjön was about 150 m^3 per year during a four-year period, i.e. 70-80 m^3 per year from both Understenshöjden and Palsternackan.

Tank trucks transporting urine to Lake Bornsjön.

Agreements between the parties

The first stage of the project aimed to establish the various components in the recirculation chain and make sure that they functioned satisfactorily. These arrangements were not always formalized in agreements between the parties.

At present, the contractor (RagnSells Agro) is responsible for the urine during the transport to the storage tanks at Lake Bornsjön, where the Stockholm Water Company assumes responsibility. No long-term contract has been signed for the disposal of the urine from the two housing estates, but the plan is to formalize the recirculation process and maintain it on a multiannual basis.

As regards permits from the authorities etc., no formal application has been made; the project has been involved in a continuous dialogue with the environmental health departments in Stockholm and the Stockholm county administrative board, and has informed them continuously about the system.

Storage prior to application

The urine is stored in tanks in order to minimize hygienic risks and be available in one place close by so that it can applied during the spring and summer. For optimum efficiency the fertilizer should be applied when sowing or during early summer in the growing crop.

At present, the urine is stored on the Stockholm Water Company's land at Lake Bornsjön in three "balloon tanks". A slight odour is noticeable when the tanks are emptied. No damage has occurred when the urine has frozen during long periods of cold, and there has been no cracking etc. The tanks are emptied by connecting a suction hose coupled to a pump in the manhole above the tanks or by gravity through connection pipes at the side of the field.

The nitrogen losses during storage in the field tanks are estimated to be no higher (0.1%) than in holding tanks that are filled from the bottom.

Table 1. Chemical composition in the middle strata of the urine tanks.

Type of tank	Place	N [g/l]	P [g/l]	N/P-quota	K [g/l]	DM %
Holding	Understenshöjden	2.8	0.24	11.7	0.89	0.70
Holding	Palsternackan	3.1	0.26	11.9	0.78	0.65
Storage	Bornsjön 2 weeks storage	2.7	0.24	11.5	0.80	0.66
Storage	Bornsjön 3 months storage	2.7	0.24	11.5	0.80	0.66

Research

Measurements of chemical, physical and hygienic parameters were carried out for a long period on urine collected at several different levels both in the holding and storage tanks, and this made it possible to record any changes in the composition and stratification of the urine.

Stratification

The concentration of nutrients and metals varied between different strata in the holding tanks. The composition in the middle of the liquid was closest to that in stirred urine. As before, the pH level was around 9. The sediment in the tanks was up to 5 cm thick after about one year of use.

The sediment is likely to increase over time, since the tanks are probably not completely emptied. When stirred, the sediment is mixed with other liquids, and this is not likely to cause any problems in future.

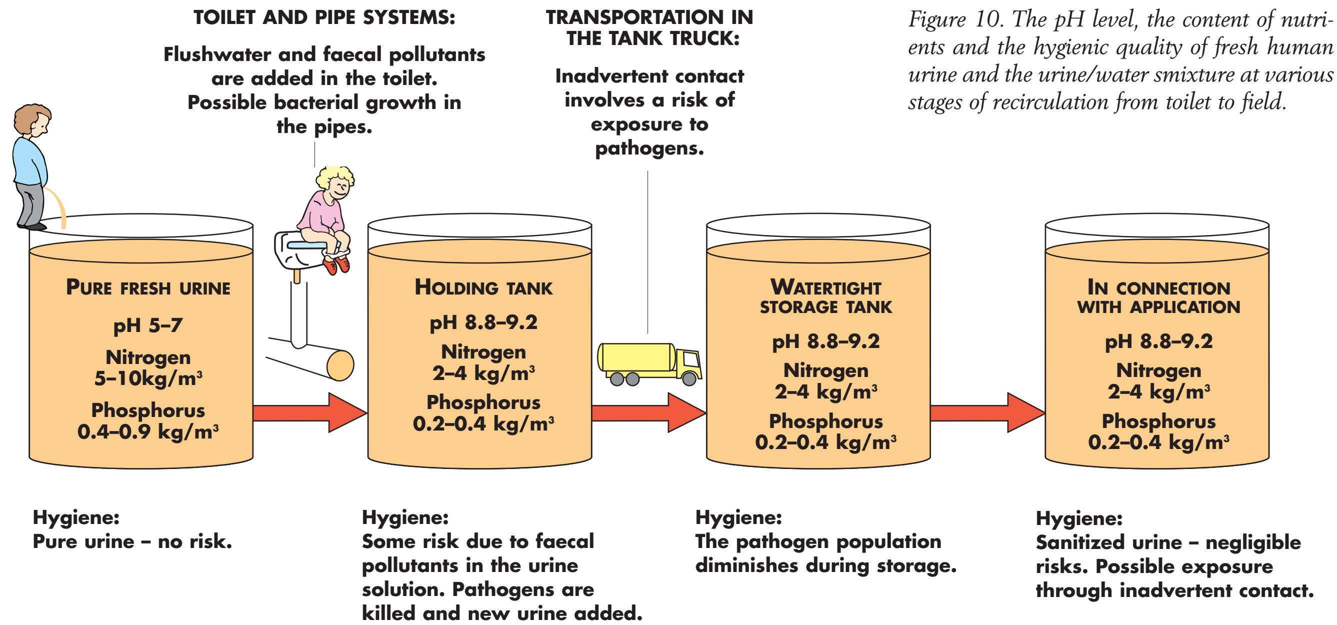


Figure 10. The pH level, the content of nutrients and the hygienic quality of fresh human urine and the urine/water smixture at various stages of recirculation from toilet to field.

CROP GROWING

At the start of the project there were many questions about urine as fertilizer. What effect did human urine have as a fertilizer? How much ammonia is lost in connection with application? Is urine poisonous to the plants? In order to be able to answer these important questions, the project focused increasingly on field trials, including analyses of yields and environmental effects. These trials were carried out for three successive years at Lake Bornsjön on land leased from the Stockholm Water Company by the farmer Henrik Pettersson.

The trials have increased the understanding of human urine as fertilizer. We now know that human urine can be a substitute for mineral fertilizer for cereal crops without causing any significant adverse effects on the crop or the environment, e.g. as regards yields, ammonia losses and the risk of nitrogen leaching.

Concise facts – human urine as fertilizer

- **Human urine is a quick-acting fertilizer that can replace mineral fertilizer in cereal crop production.**
- **The relationship between nitrogen, phosphorus, potassium and sulphur is well-balanced and, with appropriate doses, broadly corresponds to the needs of cereal crops.**
- **Nitrogen losses in the form of ammonia in connection with application were in all cases less than 10% of the amount of nitrogen applied, and usually much lower.**
- **Conventional techniques for applying liquid manure work well for human urine too. New technology is also of interest, e.g. umbilical hose systems.**
- **There is a noticeable odour while urine is being applied, but this subsides within 24 hours. At a short distance from the field the odour is not a problem.**
- **The risk of nitrogen leaching into water is no greater than when mineral fertilizer is used.**

Field trials with human urine at Lake Bornsjön.

The significance of field trials with human urine

The farmer is an important partner in connection with the recirculation of nutrients. If farmers are not inclined to cooperate it will obviously be more difficult to establish a proper nutrient cycle. Farmers who are offered human urine as fertilizer will want to know: "What is its nutrient value? What effects will the urine have on the soil and crops?"

It only became possible to answer these questions after several years of field studies of urine as fertilizer.

Advice to farmers

The grain yield when 105 kg per ha of nitrogen was applied in the form of human urine during the period 1997-99 was, before ammonia losses, equivalent to about 80-90% of the yield in a crop that received 100 kg of nitrogen in the form of mineral fertilizer.

The nitrogen in urine is volatile, and it should be stored without ventilation, for example in a covered container, and spread into or near the soil in order to minimize nitrogen losses.

Human urine can be strip-spread in growing cereal crops (up to 20-30 cm) without any toxic effects on the plants and with low ammonia losses.

The use of human urine as a fertilizer

Only a few studies have been made of the use of human urine as fertilizer in agriculture. Consequently, there is limited understanding of how human urine works and how it should be handled. There are, however, comparable fertilizers, for instance animal urine, which is applied in Sweden for agricultural purposes in amounts of about 2.3 million tonnes per year. Human urine contains more nitrogen and phosphorus, but less potassium than pig and bovine urine.

Human urine contains a high percentage of ammonia nitrogen, about 80-100% of the total content. As a result, it is quick-acting, and its effect can be compared with fertilizer with a high mineral content rather than fertilizer with a large percentage of organically bound nitrogen, such as solid manure.

Tank wagon with an applicator fitted with trailing hoses. The fertilizer is usually fed to the hoses through a centrally located distributor.

The relationship between the content of nitrogen, phosphorus and potassium is well-balanced and largely corresponds to the need of cereal crops if the dosage is appropriate. Since the pH level and the content of ammonia nitrogen is high, there is a risk of nitrogen losses in the form of ammonia gas.

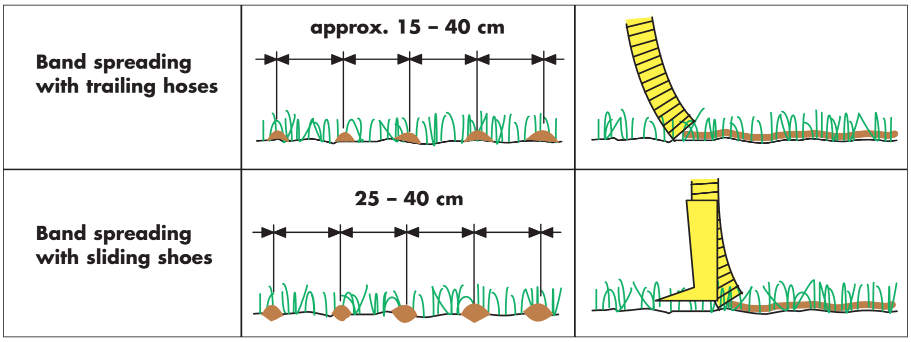


Figure 11. Diagram showing band spreading with a trailing hose boom and sliding shoes, respectively. Illustration: Kim Gutekunst

Application techniques

As with any other fertilizer, it is important to spread the urine evenly and in suitable amounts. Usually, the same technique is used for spreading urine as for liquid manure, i.e. broadcasting with a splash plate or band spreading with an applicator fitted with trailing hoses (see the above photograph and figure 11). The advantage of band spreading over broadcasting is that it causes less ammonia losses, it is not affected by the wind, there is a fixed working width and it is easier to apply the fertilizer in growing crops. By far the most common procedure for applying liquid manure is to use tank wag-

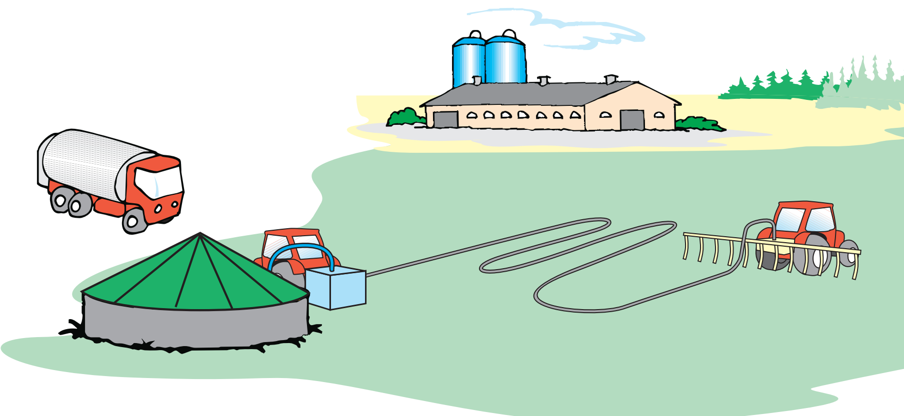


Figure 12. The fertilizer is pumped through a feeder hose system out to an applicator drawn by a tractor. This substantially reduces the damage to soil and crops since a heavy tank wagon is not used to spread the fertilizer in the field.

ons. All modern tank wagons are now equipped with a pump for emptying and spreading the contents. When spread on unplanted land, the urine can be incorporated in the soil by harrowing.

There are also applicators with sliding shoes, which incorporate the urine directly both in open soil and in growing crops (see figure 11). However, this technique is still rarely used in Sweden.

Field trials

Field trials were carried out in order to study the effects of the nitrogen in human urine on the grain yield and in order to assess the efficiency of the nitrogen, i.e. how large a percentage of the nitrogen applied that is taken up by the crop compared with mineral fertilizer.

Furthermore, measurements were made of ammonia losses after human urine was applied to the fields by means of different spreading techniques and at sowing as well as in growing crop and of the quantity of residual nitrogen in the soil after harvesting.

Samples being taken in field trials.

Table 2. The nutrient content of human urine in 1997-99 compared with pig and bovine urine.

	Dry matter content %	Total nitrogen kg/ton	NH_4-N kg/ton	P kg/ton	K kg/ton
Human urine 1997	0.7	3.7	3.4	0.30	1.0
1998					
Spring	0.5	2.6	2.1	0.23	0.85
Summer	0.5	2.4	2.2	0.22	0.80
1999					
Spring	0.8	2.3	2.3	0.21	0.73
Summer	0.4	1.9	1.8	0.14	0.53
Pig urine	0.6	0.63	0.53	0.07	1.0
Bovine urine	1.2	1.7	1.4	0.04	3.0

The trial site

Field trials were carried out at Lake Bornsjön during the period 1997-99 and exploratory trials were carried out in 1996 at Berga, south of Stockholm. In the 1997 trials the soil consisted of heavy clay that was low in organic matter while in 1998 and 99 it was a clay loam with a higher organic content.

Since 1990 the trial field has either been sown with winter wheat or lain fallow. The first year the spring was rainy and cold followed by a dry warm summer. The crop suffered from a shortage of water during the growing season. The summer of 1998, however, was very rainy and warm, which favoured the mineralization of nitrogen in the soil and as a result the effects of the fertilizer were difficult to assess.

The summer of 1999 was dry and warm, which again meant that the crop suffered from lack of water.

Implementation

In the field trials the effects of human urine were compared with those of mineral fertilizer in a barley crop. Ammonia losses were measured for various application techniques and at various times.

The nutrient content of human urine varied from year to year (see table 2), and therefore the nutrient input from human urine also varied. This may partly be because the urine that was used in the different years came from different housing areas.

The following doses of mineral fertilizer were applied to experimental plots: 30, 60, 90 and 120 kg of nitrogen per hectare. In addition, enough phosphorus and potassium was applied to ensure that the yield would not be limited by a deficiency of these nutrients.

The urine was applied either with trailing hoses or with sliding shoes (see figure 11 on p. 23). Where trailing hoses were used, the urine was spread in strips on the soil surface. Sliding shoes incorporate the urine in the soil at the same time as it is spread, provided that the soil surface is sufficiently friable. The urine that was strip-spread with trailing hoses was harrowed into the soil four hours after application.

In 1998 and 1999, application of human urine was also studied in growing crops. Various doses were given when the crop was about 20-30 cm high.

Ammonia losses were measured by a method developed at the Swedish Institute of Agricultural and Environmental Engineering in collaboration with IVL Swedish Environmental Research Institute Ltd. Nitrogen profiles indicating the content in the soil of mineral nitrogen down to a depth of 90 cm were taken before the fields were fertilized in the spring and in connection with the harvest.

Ammonia losses

Ammonia losses in connection with the application of human urine in the spring never exceeded 10% of the amount of nitrogen applied and were usually considerably lower. Table 3 below shows the losses for various doses and application techniques as a percentage of the nitrogen dose. Ammonia losses were lower where sliding shoes were used than when the urine was strip-spread and subsequently harrowed into the soil. Generally speaking, the losses after harrowing were scarcely measurable, except for the highest dose (60 tonnes/hectare). It is not possible to say what the losses would have been without harrowing.

The ammonia losses measured after the application of urine in the growing crop were negligible regardless of the application technique used. The reason for this is that the growing crop protects the soil surface from wind and sun, and the incorporation provided by the sliding shoes has no additional effect on ammonia losses. Therefore, until sliding shoes have been tried out on a larger scale in growing crops, strip spreading with trailing hoses is recommended.

Measurement of ammonia losses.

*Table 3. Ammonia losses as a percentage of the quantity of nitrogen applied per ha in spring in three different doses and, in the case of the 20 tonnes/ha dose, with the use of two different application techniques. * Harrowing after four hours.*

Method	Guideline dose t/ha	Ammonia losses, % of nitrogen applied 1997	1998	1999
Band spreading with trailing hoses*	10	6.7	2.5	7.2
Band spreading with trailing hoses*	20	5.9	2.0	4.7
Band spreading with trailing hoses*	60	9.7	2.7	1.6
Band spreading with trailing shoes	20	-	0.3	1.1

Yields and nitrogen utilization

Barley yields for different doses of human urine and mineral fertilizer are shown in figures 13, 14 and 15. The graphs show the average values for the three replications with the highest and lowest values marked. The exploratory trials in 1996 showed that the yield in plots fertilized with human urine was roughly the same as in plots fertilized with the same quantity of artificial fertilizer nitrogen.

In 1997, the yield after a dose of about 100 kg of nitrogen/ha in the form of human urine was 80% of that following a dose of 90 kg of mineral fertilizer nitrogen per hectare. Ammonia losses amounted to 5.9% (20 tonnes/ ha).

The weather in 1998 caused high nitrogen mineralization in the soil. The effect of mineralization was greater than the effects of fertilization, and there were large variations in the trials. In that year the yield in plots fertilized with human urine was greater than in those fertilized with mineral fertilizer, but the difference was small since the yield was mainly determined by other factors.

In 1999, the yield resulting from a dose of about 80 kg nitrogen/ha of human urine corresponded to 85% of that in plots fertilized with 90 kg of mineral fertilizer/ha. Ammonia losses amounted to 4.7%. The application of larger amounts of nitrogen increased the yields, which indicates that the main determining factor for the yield during that year was the fertilizer dose.

To sum up, barley yields in plots fertilized with human urine amounted to about 80-90% of those in plots fertilized with mineral fertilizer following normal nutrient doses for a spring barley crop. If the amount of nitrogen remaining after ammonia losses in connection with application is taken into account, the yields were about 80-90% of those resulting from the application of mineral fertilizer.

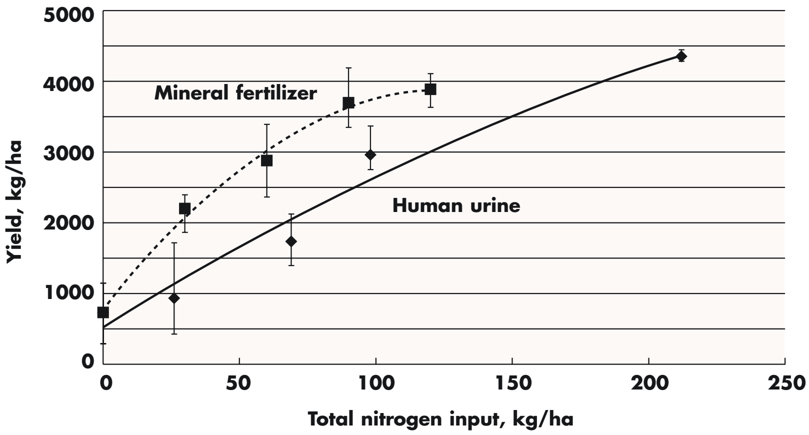


Figure 13. Barley yields in plots fertilized with human urine and mineral fertilizer, respectively, in 1997.

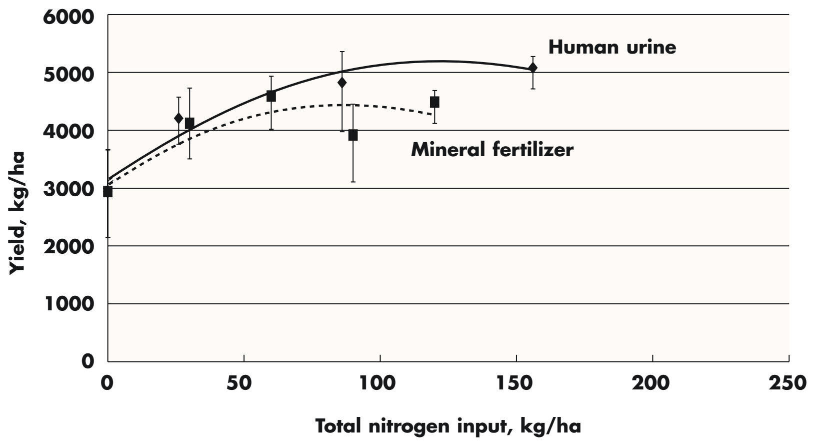


Figure 14. Barley yields in plots fertilized with human urine and mineral fertilizer, respectively, in 1998.

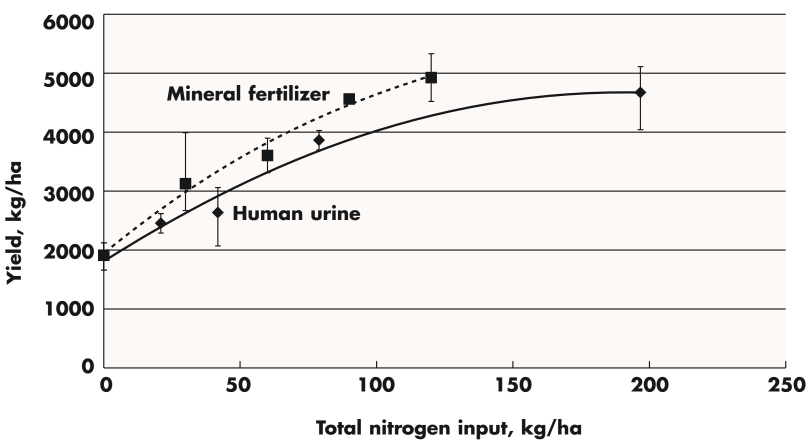


Figure 15. Barley yields in plots fertilized with human urine and mineral fertilizer, respectively, in 1999.

Timing and application techniques

Human urine should be applied to meet the nutrient needs of the crop. Where the crop is a spring cereal, this means that fertilizer could be given from the time of sowing until the crop ceases to absorb nutrients in early summer. Increasing the length of the period during which human urine is applied gives the farmer/contractor greater freedom.

The field trials demonstrated that yields in plots that were fertilized when the crop was 20-30 cm high did not differ significantly from those in plots where fertilizer was applied in the spring. An initial dose of 30 kg of artificial fertilizer nitrogen was, however, necessary when applying the urine in the growing crop in order to give the crop a good start. There was no indication that the application of human urine had any detrimental effects on the growing crop.

Yields were also affected by the application technique that was used. When the urine was applied in spring, yields were higher in plots where it was applied with sliding shoes than when it was band-spread by trailing hoses and then harrowed in. This effect was not observed when the urine was applied in the growing crop.

Mineral nitrogen in the soil – low risk of loss

Samples were taken prior to spring sowing and after the harvest of the content of mineral nitrogen in the soil. The samples showed that the risk of nitrogen leaching is no greater with human urine than with mineral fertilizer.

There was a tendency in 1999 for higher doses of both types of fertilizer to increase the quantity of mineral nitrogen in the soil, but there was no evidence of this in 1997 and 1998.

The quantity of mineral nitrogen that remained in the soil after harvest was 15-26 kg/ha in 1997 and 1998 and 22-41 kg/ha in 1999. These levels are consistent with normal results in other field trials.

The Stockholm Water Company has measured nutrient leakage in the Bornsjön area continuously ever since 1985, and no change has been observed in the leakage pattern.

Nutrient balances

Nutrient balances are quick and reliable indicators of nutrient flows. Nutrient balances can be used as a basis for action by both farmers and society as a whole to ensure economic use of nutrients and reduce air and water pollution. Nutrient balances indicate the flow of nutrients in the crop and enable farmers to achieve more efficient utilization of nutrient inputs and minimize the environmental impact of crop growing.

Human urine and mineral fertilizer differ in terms of nitrogen utilization. Crops fertilized with human urine containing 98 kg of nitrogen per ha in 1997 absorbed 44% of the nitrogen input. The corresponding figure for mineral nitrogen in the same year was 61%. The figures for 1999 were 70% and 83%, respectively. This indicates that crops absorb less of the nitrogen in human urine compared with artificial fertilizer, and more remains in the soil. This nitrogen surplus may either be released into air or water by denitrification or leaching, or it may be stored in the organic material in the soil.

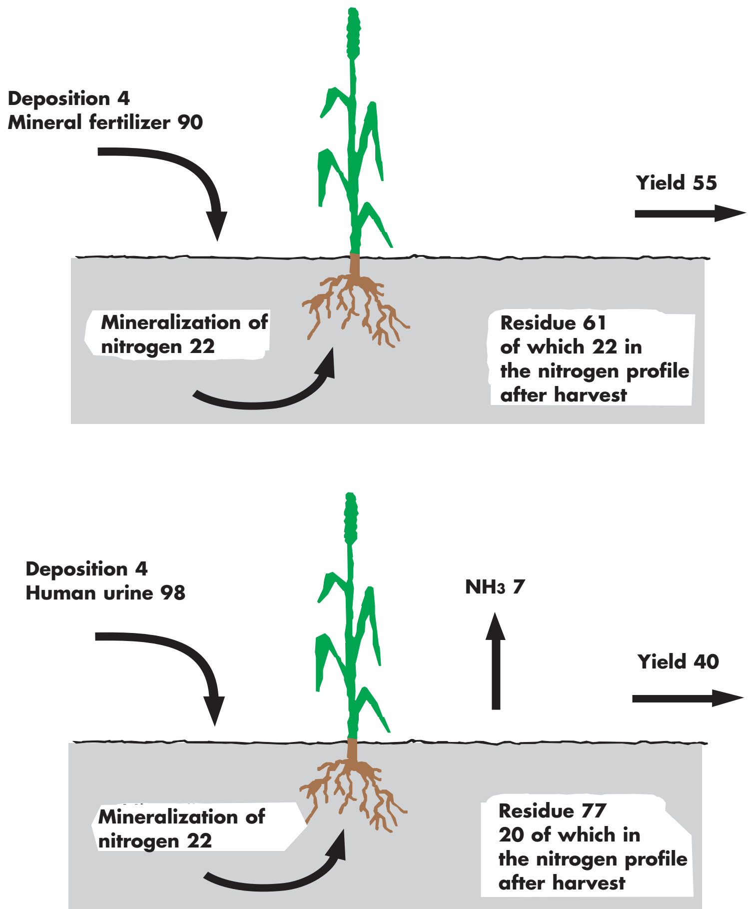


Figure 16. Nutrient balances in crops fertilized with mineral fertilizer and human urine, respectively, in 1997. All the figures in the diagram represent kg of N per ha and year.

HYGIENE AND PROTECTION AGAINST INFECTION

Urine in itself presents virtually no risk of infection. But it can be contaminated by pathogens present in faeces. It was widely feared that the establishment of a new system involving a fertilizer that had not previously been studied might give rise to new and possibly unacceptable infection risks. Today, we know more about the hygienic aspects of urine separation than we do about other wastewater systems, including conventional systems. If appropriate measures and precautions are taken, and if the recommendations for storage and application are followed, the hygienic risks associated with urine separation are very small.

Concise facts – hygiene and protection against infection

- **Urine in itself presents a negligible hygienic risk.**
- **Faeces that enter the urine bowl can contaminate the urine.**
- **Many pathogens are killed during storage.**
- **Recommendations have been issued for storage times and suitable crops (see p. 29).**

Figure 10 on p. 21 shows some of the transmission routes at various stages of the recirculation of urine to farmland. There are as yet no rules for the handling and use of source-separated human urine. Our proposals represent recommendations based on the findings of the research projects that have been carried out.

If the recommendations for application etc. are followed, urine can be used on all crops if it is stored at not less than 20°C for at least six months.

Measures to reduce infection risks

Infection risks in connection with urine separation can be minimized by taking the measures listed below.

Pre-treatment

Storage eliminates or reduces the number of pathogens in the urine. The reduction is greater if the urine is stored for a long time, at high temperature, with a high concentration of nitrogen and a high pH level in the solution.

Application techniques

Steps should be taken to reduce the formation of aerosols (dispersions of small drops of water forming a mist) and the exposure of the farmer in connection with application. Incorporation of the urine into the soil, application close to the ground and harrowing soon after application reduce exposure.

Restrictions with respect to crops

If the recommendations concerning application techniques are followed, urine can be used for all crops if it has been stored at not less than 20°C for at least six months and for all crops except food crops that are to be consumed raw if storage takes place at not less than 4°C for at least six months.

Choice of site

Choosing a suitable site and time for the handling and application of urine helps to minimize the exposure of people and animals in the area.

Avoiding risk groups

Given the present state of knowledge, urine should not, as a precautionary measure, be collected in places where the excretion of pathogens and medicines is known to be higher than normal in the population, e.g. hospitals and homes for the elderly.

Adjustment to the size of the cycle

Greater caution should be exercised when it comes to storage routines for large systems. For private households, and for private use, the urine should be incorporated into the soil and food crops should not be fertilized for a period of one month prior to harvesting.

Research

To be able to assess the risks associated with the handling and application of source-separated human urine, it is necessary to know what happens to the pathogens that may be present in the urine mixture. Therefore, studies were made of the survival of various microorganisms both in field trials and in laboratory experiments designed to simulate the process in the storage tank.

The number of pathogens is reduced in both holding and storage tanks, the difference being that in holding tanks new pathogens may constantly be added, while by definition the storage period starts after the last addition of fresh urine mixture.

Recommendations for the storage of urine prior to application will be found in the table below. The recommendations apply both to application prior to sowing and in the growing crop. They were published in their entirety in Swedish Water and Wastewater Association Report 2000:1.

Viruses and protozoa can survive for a longer time in the urine mixture than bacteria, but they cannot survive the treatment to which cereals and oil plants are subjected in connection with processing or heat treatment for the production of food or animal feed. Such crops can therefore be fertilized with human urine despite the possible presence of viruses and protozoa.

Virus pathogens in the gastro-intestinal system of humans are not transmitted to animals, so urine can also be used for other forage crops if viruses are the only pathogens that have survived storage.

In the case of food crops that are consumed raw, it is recommended, as a safety barrier, that a withholding period of one month should be observed between fertilization and harvesting and that the urine be incorporated into the soil.

Table 4. The relationship between storage conditions, the pathogen content of the urine mixture and recommendations for crops in larger systems a).

Storage temperature	Storage period	Presence of pathogens in the urine mixture b)	Recommended crops
4°C	≥ 1 month	Viruses, protozoa	Forage and food crops that are to be processed
4°C	≥ 6 months	Viruses	Food crops that are to be processed, forage crops c)
20°C	≥ 1 month	Viruses	Food crops that are to be processed, forage crops c)
20°C	≥ 6 months	Probably none	All crops d)

a) "Larger systems" in this case means that human urine is used to fertilize crops that are consumed by persons other than the members of the household where the urine is collected.

b) Gram-positive and sporulating bacteria are not included.

c) Except grassland for the production of animal feed.

d) In the case of food crops consumed raw it is recommended that fertilization with urine be discontinued at least one month prior to harvesting and that the urine is incorporated into the soil.

COMPARISONS WITH OTHER WASTEWATER SYSTEMS

Is it possible to say which wastewater treatment system is best?

It is difficult to compare new wastewater systems with existing ones, since we do not have any large-scale examples of urine separation systems that serve a community as a whole.

Therefore, in order to assess whether urine separation enhances the wastewater treatment system we must rely on existing data and assess, with the use of models, the effects on the environment and resource management of various treatment systems.

Although simulations are not measurements of actual systems, they can provide useful information which cannot be obtained in real life. Models and simulations make it possible to compare various system solutions on the basis of equivalent conditions. The systems that are compared should have the same function, e.g. to supply the same amount of nutrients to farmland.

How comparisons were made

The treatment system in the Palsternackan estate was modelled and its effects on the environment and natural resource management were simulated. ORWARE, a computer model developed to simulate the production, treatment and handling of solid and liquid organic waste, was used for the simulations.

The following two treatment systems were compared in the simulations

The system currently used in the Palsternackan estate, i.e. urine separation combined with the conventional sewage treatment system in Stockholm for the faecal fraction and greywater.

The conventional system, in which urine and the accompanying flushwater enter the conventional sewage treatment system in Stockholm.

The Henriksdal waterworks in Stockholm ensures state-of-the-art, efficient removal of phosphorus and nitrogen.

Table 5. The parameters used in the simulations, which are very close to actual conditions in the Palsternackan estate.

Parameter	Basic data
Transport distance	33 km
Nitrogen removal by the sewage treatment plant	80%
Sludge to farmland	50%
Time spent at home by residents	65% (15.6 hours a day)
Degree of urine separation	65%
Flushwater	0,1 l/flush
Simultaneous flushes a)	66%
Nitrogen losses (total) b)	5%
Plant availability of the nitrogen in the urine	100% c)
Plant availability of the phosphorus in sludge and urine	100%

a) The percentage of urine flushes that are accompanied by practically simultaneous flushing of the faeces bowl.

b) During the handling, including application, of urine.

c) The availability of the nitrogen in urine varied in field trials between 80% and 100%.

Concise facts – effects on the environment and resource management

- The effects of various treatment systems on the environment and resource management can be assessed by modelling and simulations.
- In nearly all cases, urine separation appears to reduce the environmental impact compared with conventional treatment systems.
- Urine separation increases the recirculation of nutrients; in addition, emissions of eutrophic substances are lower compared with conventional systems.
- The urine can be transported as far as 220 km with a tanker truck and trailer before the estimated energy consumption exceeds that in conventional systems.

These two systems were compared with respect to their simulatedeffects on the environment and natural resource management. The parameters used in the simulations are presented in Table 5.

Results of the simulations

The results of the simulations carried out within the framework of the research projects are presented below. The research reports deal with several other aspects and contain more exhaustive discussions than those summarized here.

Aspects compared

- Emissions of phosphorus into water
- Emissions of nitrogen into water
- Emissions of heavy metals into water
- Quantity of nutrient recirculated
- Inputs of heavy metals in farmland
- Energy use

Protection of recipient systems – emissions of nutrients

The use of urine separation as a complementary technology reduces emissions of nitrogen into water by a little more than a half compared with the conventional system. Emissions of phosphorus are probably lower too, but not as much, since the conventional system is very efficient when it comes to removing phosphorus.

Recirculation of nutrients

Urine separation increases the recirculation of nutrients, in particular of nitrogen and potassium, compared with the conventional system. The recirculation of phosphorus increases too, but not to the same extent.

This is because a large percentage of the phosphorus is precipitated into the sludge, and an estimated 50% is recirculated to agriculture. If the sludge is not recirculated, urine separation also substantially increases the recirculation of phosphorus.

Nitrogen and phosphorus are nutrients that tend to be lost in the conventional wastewater systems of today, or to cause eutrophication. Urine separation makes it possible to use them to fertilize farmland instead.

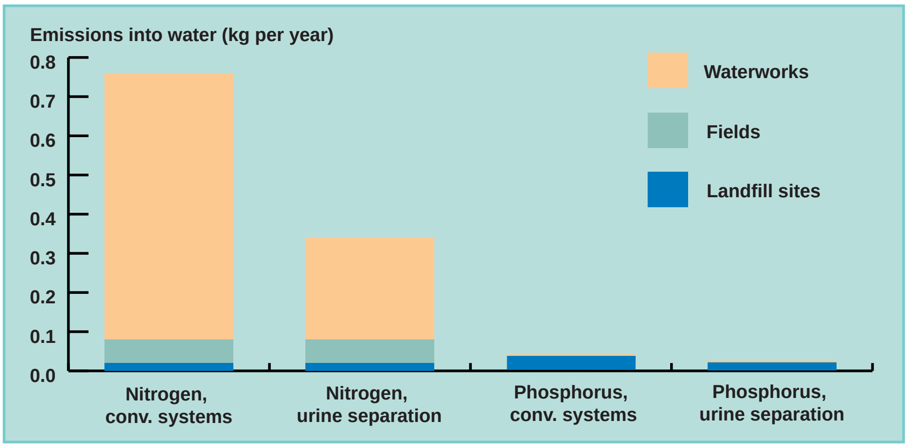


Figure 17. Emissions from housing of nitrogen and phosphorus to water with conventional wastewater systems and urine separation systems, respectively. It is assumed that 50% of the sludge is used as fertilizer on farmland.

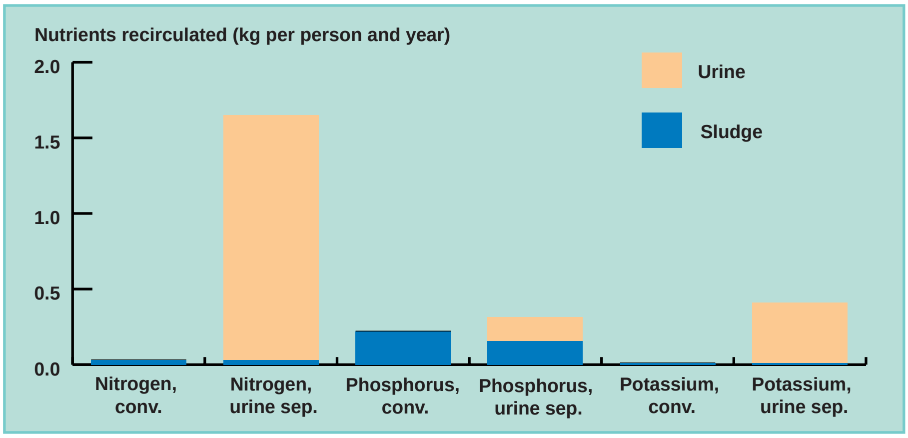


Figure 18. Quantities of plant available nutrients that are recirculated with digested sludge and source-separated urine to farmland from household wastewater in conventional and urine separation systems, respectively. It is assumed that 50% of the sludge is used as fertilizer on farmland.

Recirculation of heavy metals

As regards the recirculation of heavy metals to farmland, the differences between the two systems are small, since the urine mixture contains very small amounts of heavy metals. The estimated copper levels in the urine mixture are based on measurements in the Hushagen district in the town of Borlänge, since all the pipes in the urine pipe system there are of plastic, which should be used for all new systems. If, instead, the simulations are based on copper seals, which are used in the Palsternackan estate, the flow of copper in the urine solution should be roughly the same as the copper flow in the 50% of the sludge that is applied to farmland.

Urine can be transported as far as 220 km by tank truck and trailer before energy consumption exceeds that in the conventional system.

Energy use

Urine separating systems consume less energy than conventional systems, assuming that the treatment plant ensures efficient nitrogen removal and that mineral fertilizer is used to provide supplementary nutrients. This is the case provided that the urine is not transported further than 95 km by sludge suction truck or 220 km by truck and trailer. Urine separation systems increase the consumption of diesel and other fuels, but reduce the consumption of electricity in sewage treatment plants and of energy for the production of mineral fertilizer.

Figure 19 shows that most urine transports by tank truck consume less energy than the total amount of energy consumed by conventional wastewater treatment systems and the manufacture and application of mineral fertilizer with a corresponding nutrient value as that of the urine spread.

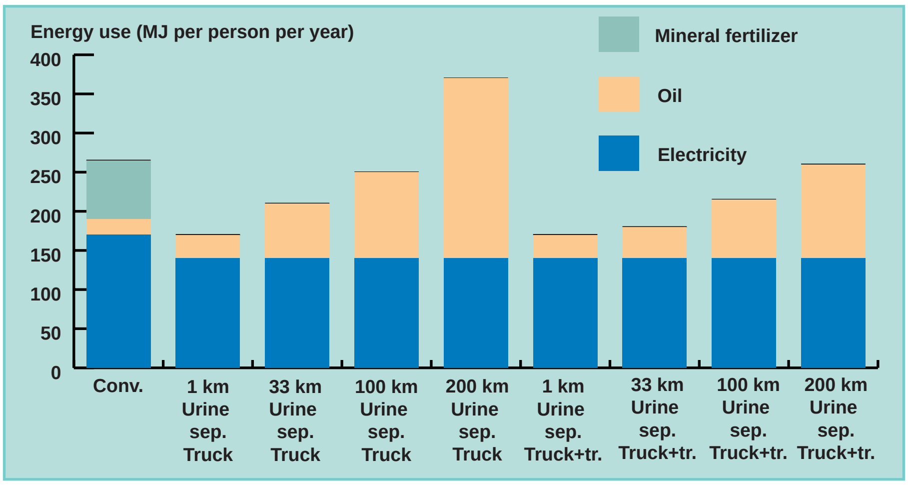


Figure 19. The distances the urine mixture is transported and the method of transportation determine total energy use, i.e. net use of electrical energy (electricity use minus electricity generation), oil and energy for the production and distribution of mineral fertilizer.

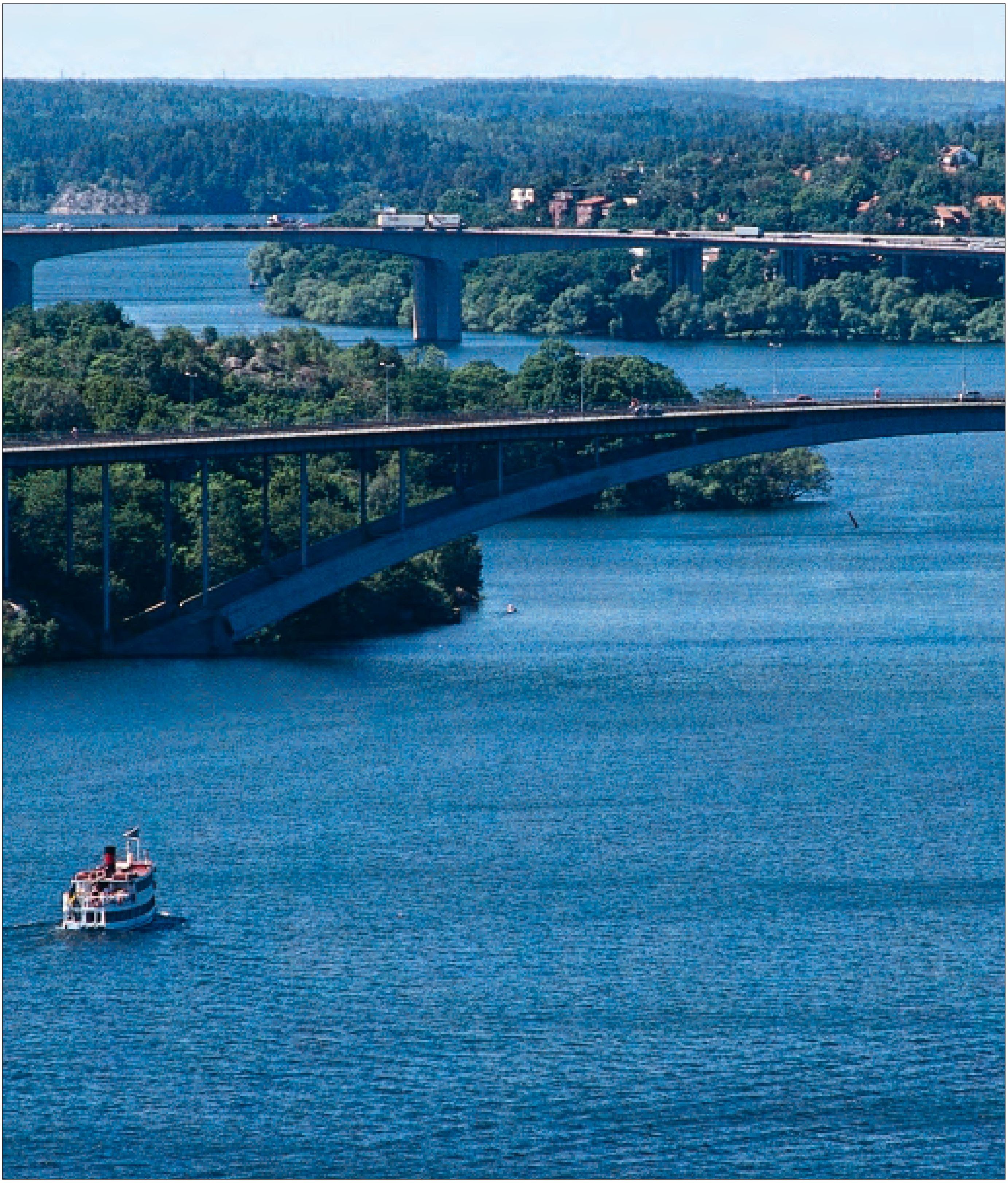
Decision guidance data for the future

The results of simulations are not absolute certainties. They indicate trends and approximate magnitudes. It is therefore interesting to note that several other studies have indicated similar trends.

Although urine separation reduces the environmental impact and improves resource management, this does not necessarily mean that we should immediately convert all existing sewage treatment plants. A number of other factors must be considered before any action is taken to modify our sewage treatment systems.

Examples of such factors are economic parameters, legal and organizational aspects and of course the status of the existing system and when major new investment will be necessary.

Nevertheless, the results of systematic environmental analyses such as those carried out within the framework of these and other projects give us much better guidance data than were previously available for discussions about the design of the wastewater treatment systems of the future.



Our wastewater systems must, in order to be sustainable, meet high standards of hygienic safety, protect our lakes, streams and seas and make it possible to recirculate plant nutrients to farmland.

QUESTIONS AND ANSWERS ABOUT URINE SEPARATION

By way of a summary of the report, a number of frequently asked questions about urine separation are answered in this chapter. These appear under the headings: Infection risks and sanitary conditions, Environmental impact and resource management, and Technical, social and economic aspects.

INFECTION RISKS AND SANITARY ASPECTS

DOES URINE SEPARATION INVOLVE ANY HYGIENIC RISKS?

Since most pathogens occur in the faecal fraction, which is treated in the normal way, there is no appreciable difference between the risks associated with a urine separation system compared with a conventional system. If the workers who handle the urine are careful and the recommendations for storage and risk minimization are followed, we consider the hygienic risks of urine separation to be negligible. When it comes to hygienic risks, it should, however, be pointed out that nothing is completely risk-free.

HOW LONG DO THE BACTERIA AND VIRUSES IN URINE SURVIVE?

Bacteria, viruses and other pathogenic microorganisms may be present in the urine if faeces get into the wrong toilet bowl. Many pathogens are killed when the urine is stored. The time it takes depends on the original quantity of pathogens and on storage conditions. Pathogens die more quickly in higher temperatures, higher pH levels and a more concentrated urine mixture. Most bacteria die quickly (within a few days), while the number of viruses does not diminish at all at lower temperatures.

DO MEDICINE RESIDUES REPRESENT A RISK IN HUMAN URINE?

The presence of medicine residues, for example antibiotics and hormonal substances, is an important issue which affects all types of wastewater systems and organic fertilizers. Medicine residues may be present in urine, faeces, animal manure and the sludge produced by sewage treatment works.

Almost all substances that occur in medicines are degraded by the microor-

ganisms that are naturally present in the soil and absorption by the plants is probably negligible.

The risk when these substances are being released into the water environment, which occurs in the conventional sewage treatment works, is probably greater. There is insufficient understanding of this field and more research is needed. In our view, medicine residues are not an obstacle to the introduction of urine separation systems.

ENVIRONMENTAL IMPACT AND RESOURCE MANAGEMENT

WHAT EFFECT DOES SOURCE-SEPARATED HUMAN URINE HAVE ON NUTRIENT EMISSIONS?

When a urine separation system is established, nitrogen emissions into water are reduced by about 60% irrespective of the type of treatment. As regards phosphorus, the reduction depends on the type of treatment of the wastewater as a whole. Where the treatment plant ensures efficient phosphorus removal, the reduction in emissions is small, but if the plant cannot remove any phosphorus at all the reduction may be almost 50%.

HOW MUCH WATER DOES URINE SEPARATION SAVE?

The determining factors for the amount of water saved by a urine separation system are the amount of water used for flushing the urine and the faeces, respectively, how often the toilet is flushed and how toilet paper is dealt with after use.

Since the two bowls are flushed separately in Dubbletten toilets, any toilet paper used after urination must either be flushed down with the faeces, placed in the rear bowl, which is flushed as the need arises, or collected in a waste basket beside the toilet. Therefore, the amount of water saved may vary between 5-40 litres per person per day depending on individual habits and the toilet with which the comparison is made.

Since the amount of water saved depends on how the toilet is used, the users' motivation and understanding is crucial.

HOW MUCH PLANT NUTRIENT IS RECIRCULATED TO FARMLAND WHEN A URINE SEPARATION SYSTEM IS USED?

Assuming that residents spend an average about 15 hours at home every day, about 1.6 kg of nitrogen and 0.2 kg of phosphorus is recirculated per person per year. In the case of highly motivated residents, this may increase to as much as 2-2.5 kg of nitrogen and 0.25 kg of phosphorus per person per year. By way of comparison it may be mentioned that the amount of fertilizer needed for one hectare under cereals is about 90 kg of nitrogen, which corresponds to the urine collected from about 50 people in one year.

HOW DOES ENERGY CONSUMPTION IN A URINE SEPARATION SYSTEM COMPARE WITH THAT IN A CONVENTIONAL SYSTEM?

There is no simple answer to this question, since conventional systems vary greatly in terms of energy consumption. Generally speaking, in an efficient urine separation system located less than 100 km from the land where the fertilizer is used, the fertilizer value of the urine in itself represents a saving in energy compared to mineral fertilizers and taking into consideration transportation and application. The reduction in wastewater treatment volumes and which also saves energy, and the reduction in nutrient discharges into water can in that case be considered a bonus from the environmental point of view.

How much nitrogen is lost in a urine separation system from toilet to field?

Where the system is properly designed nitrogen losses are very small, less than 1% from the toilet, via holding tanks, transportation and storage to application. The losses associated with application are less than 10% and may, if the best available technology is used, be as low as 1-2%.

How can human urine be used in agriculture?

Human urine should be used as a quick-acting nitrogen fertilizer that contains balanced quantities of phosphorus and potassium. The urine can be applied using tried and tested methods for the application of liquid manure.

What is the effect of human urine fertilizing

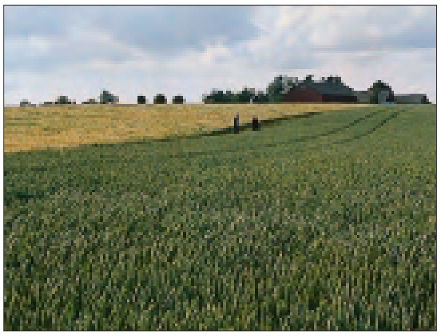
The effect of human urine applied to a spring crop corresponds to 80-90% of the effect with the same amount of nitrogen in the form of mineral fertilizer. Human urine can be applied in the growing crop with good results.

Technical, social and economic aspects

What is the biggest problem associated with urine-separating toilets?

The main problem in today's urine-separating toilets consists of a number of small details which affect the convenience and function of the toilets. Improvements are needed in the following areas:

- There is a need to improve the urine bowl and the partition in both the toilet models that were studied, so that it is easier for men to urinate in the right bowl, without splashing, even if they do so in a standing position.



- The flushing of the urine bowl and the entire surface of the partition must also be more effective, although the amount of flushing water used should not exceed 1-2 dl a time.

- The Dubbletten toilet seat needs to be improved; it must be comfortable and functional, it must not crack and it should have standard mounting dimensions.

- The design of the toilet seal in the Wost Man Ecology DS model should be changed to make it possible to use a mechanical snake when necessary and to replace the seal easily. There should not be any dead volumes that make it impossible to clean any part of the toilet. It should also use less water to flush the toilet and the partition between the two bowls should be higher so that water does not normally flow from the faeces bowl to the urine bowl.

What should the capacity of the urine tank be when urine separation is introduced in a housing estate?

On average, the amount of urine mixture collected by the Dubbletten model is 1.5 litres per person per day, while the Wost Man Ecology DS model produces 2.5 litres. The capacity of the holding tank does not need to exceed one and a half times the maximum collection volume of the tank truck. The system can vary in design depending on the location of the storage site and the farmland where the urine is to be applied.

Are urine-separating toilets more expensive to install when a building is converted?

It is more expensive to install urine-separating toilets than conventional toilets. However, it may be the cheaper alternative when it comes to meeting the need to reduce water emissions and/or recirculate a high proportion of plant nutrients.

Is it possible to charge for the use of urine as a fertilizer today?

No, but it may be possible in future if and when human urine is approved for organic farming by the European Union.

Since no similar system has been installed anywhere else, estimates of the cost of transportation and treatment are uncertain. Often, but not always, the residents themselves have to pay for the collection and transportation of the urine.

Do farmers require permits to use human urine as a fertilizer?

No, but farmers should check with those who buy their products that there are no restrictions as regards the marketing of products that have been fertilized with human urine.

What is the greatest environmental advantage of urine separation today?

Although urine separation systems are better than other systems from the environmental point of view and are a feasible proposition in urban areas, in the short term they are most useful as a complement to individual sewage treatment systems. A substantial increase in the use of urine separation systems in detached houses would make an enormous difference to the environment. The less efficient the existing wastewater system, the more difference a urine separation system will make.

SUMMARY OF ADVICE AND RECOMMENDATIONS

The recommendations generated by the R&D projects are primarily aimed at three target groups with key roles in the planning, construction and operation of urine separation systems:

1. **Residents, building owners and housing managers**
2. **Local politicians and officials**
3. **Farmers**

Residents, building owners and housing managers

- It is important to contact the municipal environmental health and public works departments at an early stage in order to facilitate the planning of the systems.

- Contact farmers and farmers' organizations etc. at an early stage of planning in order to conclude long-term agreements to ensure that the urine will be disposed of.

- Assume that organizing the recirculation of urine to farmland will cost a certain amount of money.

- Residents must be properly informed about the functioning of their toilets and the system as a whole and why the urine separation system was chosen. This has a significant impact on the amount of urine that is actually separated and the amount of water saved.

- Ecolabelled cleaning products are recommended, and it is important not to use any chemicals in the toilet. In order to save water, toilet paper that is used after urination should be placed in a waste basket or in the rear bowl of the toilet for subsequent flushing.

- Most of the stoppages that occur in the toilet seals are easy to clear, and the harder stoppages can be dissolved with the help of a concentrated caustic soda solution.

- We do not yet fully understand the long-term effects of the formation of sludge in pipe systems, but studies indicate that any future problems will not be significant. It is difficult to avoid the formation of sludge, but this should not cause a problem if the inclination of the pipe system is at least 1% and the diameters of the pipes at least 75 mm (or even better 110 mm) in the case of horizontal pipes, leaving plenty of scope for inspection and flushing.

Local politicians and officials

- The municipality has a key role in coordinating housing companies, farmers and other parties concerned, for example for the conclusion of long-term agreements between housing managers/households and farms. Expertise is often available in public works departments about systems for the handling of organic residues.

- The contents of a urine tank should be stirred in order to allow representative sampling of the nutrient content. Where this is not feasible, it is recommended that a sample be taken from the middle of the urine mixture.

- The infection risks associated with the handling of the urine mixture are due mainly to faecal contamination. Analyses of the traditional indicator bacteria (coliforms, E. coli, enterococcus and clostridia) cannot be used to measure the hygienic quality of the urine mixture. The bacterial growth in the sludge that forms in the pipes increases the content of enterococci, in particular, in the urine solution, and as a result the bacteria do not reflect the true faecal fraction.

- The environmental benefits of urine separation systems in housing depend mainly on the standard of the rest of the wastewater treatment system, the percentage of urine separated and the amount of time spent at home by residents. In any case, discharges of both nitrogen and phosphorus are reduced by a urine separation system. The nitrogen lost in connection with the collection, transportation and storage of urine can, with proper installation, be kept to a minimum (<1%).

Farmers

- An agreement should be drawn up with a contractor or representatives of the housing estate in order to clarify the division of responsibilities and economic matters, where applicable. This agreement should contain detailed routines and instructions for the collection of urine in the housing estate, transportation and storage/application.

- The contractor, be it a company or a farmer, should be required to supply documentation (the date of collection, volume, sampling, cleaning of the tank truck, destination of the urine and the driver). The farmer should also have access to a well-informed contact and the contractor should have a quality-assured organization.

- Human urine is a complete fertilizer that contains both macronutrients and micronutrients and only very small amounts of heavy metals. In trials, cereal yields fertilized with urine were 80-90% as high as those fertilized with mineral fertilizer.

- The preferred application technique for urine is to incorporate it into the soil as soon as possible after application. This minimizes nitrogen losses and reduces the risk of odour nuisances and the spread of infection.

- The urine dose is normally calculated on the basis of the nitrogen input required.

- No plant toxic effects have been observed in connection with the fertilization of cereals. Urine is not a suitable fertilizer for seeded grassland on account of high ammonia losses in connection with application and a possible risk of plant toxic effects.

- Human urine can be spread by using the application techniques used for liquid manure.

- Field trials show that human urine can be applied in the growing crop without any appreciable adverse effects. This means that the time of application can be prolonged from the beginning of May to mid-June (in the central Swedish agricultural belt).

- When urine is being applied, a characteristic odour is noticed by people standing in the field, but at a short distance this is not a problem. The urine permeates the soil after spreading, and any odour nuisances soon subside.

- Farmers are generally familiar with the handling of organic fertilizers of various kinds. The necessary machinery and farmland are already available. Many farmers may be able to find a niche in the future as local ecological entrepreneurs, responsible for collecting, storing/treating and applying organic residues from households.

- Human urine is only one of several possible fertilizers in this connection. However, this potential can only be utilized if farmers keep abreast of the latest advances in this field.

Connection pipe used by tank trucks to fill the storage tanks at Lake Bornsjön.

WHAT MORE DO WE NEED TO KNOW?

The urine separation systems that have been installed function quite well, but there is a need for a steady increase in the number of installations of new systems in housing estates and thorough monitoring and evaluation. No large-scale R&D projects relating to urine separation systems are under way in Sweden today. Research is, however, being done on matters related to urine separation, such as measurements of hormone-disturbing substances in various fractions of wastewater, experiments with techniques for concentrating urine etc.

Some areas that the project participants considered of particular interest for future study are mentioned below. They include both pure research and issues of a social and political nature.

Human urine in organic farming

There is nowadays a demand among organic farmers for quick-acting fertilizers such as human urine. However, EU rules prohibit the use of human urine in organic farming. If these rules were changed, this would help to solve the problem of disposing of the urine and possibly also improve the economic incentives for recirculating it in agriculture. We regard this as a priority issue, although essentially a political one.

Hygienic risks

The hygienic risks associated with the management chain proposed in this report – careful source separation, separate holding and storage – have been thoroughly investigated, but further study of the survival of parasites may be necessary.

As regards assessments of the infection risks in developing countries, additional studies will be needed of microorganisms that are typical of such environments. Pathogens are probably killed much faster in warm climates, but no studies have been made in this area and further research is necessary.

The presence of medicine residues in urine

A preliminary study published by the Swedish Environmental Protection Agency (1996) indicates that medication does not represent a significant environmental risk in connection with the use of urine as a fertilizer.

The present projects did not include any studies of medicine residues. Additional research in this area should focus on the concentrations of active substances and their metabolites in excreted urine and their degradation in soil.

Comparisons should be made with the situation as regards wastewater, sludge and manure, and they should include the degradation of synthetic antibiotics. These are probably some of the most important elements of the research that is needed in order to obtain EU approval for the use of human urine in organic farming.

Field trials

Depending on local conditions and demand, various crops might be considered for fertilization with human urine, and it is therefore worthwhile conducting field trials. The relatively high content of chlorides in urine makes it necessary to carry out field trials for different crops.

Sanitary engineering and dimension specifications

Preliminary recommendations on the dimensions and design of pipes and tanks in urine separation systems are presented in this report on the basis of observations and measurements in systems that are two to three years old.

The functioning of both existing and new systems must continue to be monitored in order to acquire the necessary experience and, where necessary, to change or supplement the recommendations. There is particular uncertainty about the diameters required for horizontal pipes with an inclination of at least 1%. However, feedback of experience is necessary throughout the system.

According to some reports, the pipe seals in urine systems become brittle, which makes it difficult to seal the pipes properly in connection with repairs. This suggests that the ageing properties of pipes, gasket material and tank materials need to be studied.

The long-term function of the toilets and pipe systems

Stoppages that block toilet seals are a problem that calls for continued research. Further studies should also be made of long-term deposits in flexible seals and the function of various water-free odour barriers that are available in the international market.

The long-term development of pipe systems should be monitored and evaluated. If urine separation is to be an attractive alternative, the toilets need to be improved. Obviously, they must be comfortable to sit on and they should be supplied with proper instructions for installation and use.

Investment costs

One great disadvantage connected with urine separation is that it is expensive to install new pipes both in buildings and in the ground. Since the flow in urine separation systems is low, the possibility of making simple and cheap additions to existing sewer pipes should be investigated.

The goal should be to develop simple systems, preferably ones that do not require excavation, as a complement to existing pipes. Where a gravity system is used, horizontal urine pipes should be relatively thick, at least 75 mm in diameter, but a much smaller diameter can probably be used if the urine flows through pressure pipes. The development of cheaper tanks is another desirable goal, as well as the development of flexible tanks that can be installed, for example in foundations with crawl spaces that are sufficiently large, without the need of excavation.

How should we treat the remaining wastewater?

The source separation of urine and/or faeces changes the composition of the remaining wastewater and thus the treatment conditions and requirements.

Research should be undertaken into appropriate treatment techniques in both small- and large-scale systems.

Dissemination of knowledge

We now know a great deal about urine separation systems, in fact in some areas we even know more than about conventional systems. It is important to pass on this information to the water and sewerage sector as a whole, but also to a larger group of people, including politicians, officials in local authorities and government agencies, farmers etc. Otherwise there is a risk that decisions will be based not on the state of the art but rather on excessively negative or positive assessments about how these relatively new systems function.

Responsibility for further research and development

Research and development relating to urine separation systems was undertaken in the 90s by committed individuals in the eco-construction movement, technology suppliers, housing companies, individual municipal water and sewerage companies and researchers.

During these years they developed great expertise and unique products which are now in demand in international markets. Government R&D funds made a rather small contribution to this development, and much of the costs were borne by parties who had no obligation to pursue this activity. As the economic climate has become harsher, many of those involved in this process can no longer finance such projects.

The companies, organizations and universities that took part in these projects now realize that the role of financier must be assumed by others. Research and development relating to future wastewater treatment systems must be conducted and financed by those who are responsible for long-term development. In other words, this issue must be addressed at governmental level.

TECHNICAL TERMS AND ADDRESSES

Technical terms used in the report

Urine separation	A system for separating urine before it is mixed with the wastewater flow.
Blackwater	The wastewater from toilets.
Greywater	Wastewater from baths and showers, washing up and clothes washers.
Single-flushing toilet	A toilet in which the urine is flushed with water and other material is treated without water, for example by composting.
Dual-flushing toilet	A toilet in which urine and faeces are flushed separately.
Macronutrients	Nutrients that are needed in substantial amounts by plants, e.g. nitrogen, phosphorus, potassium and sulphur.
Micronutrients	Nutrients required by plants in small quantities, e.g. manganese.
N	Nitrogen, a plant nutrient that causes eutrophication in lakes and seas.
P	Phosphorus, a plant nutrient that causes eutrophication in lakes and seas.
K	Potassium, a nutrient that is not known to have eutrophying effects in water environments.
BOD	Biological Oxygen Demand, a measure of the amount of oxygen-consuming substances in wastewater.
Mineral fertilizer	Commercial fertilizer, i.e. industrially produced fertilizer.
Pathogens	Microorganisms that can cause disease.
Protozoa	A group of microorganisms, some of which cause infections in humans.
Gram-positive and sporulating bacteria	Bacteria with special properties that enable them to survive extreme conditions.
Indicator bacteria	Bacteria that are measured for the purpose of assessing the hygienic quality of water (e.g. E. coli and coliforms).
Withholding period	Identical with the storage period, i.e. the minimum period that must elapse between fertilization and harvest.
Grain yield	The part of the harvest that consists of grains.
Cereal	Barley, oats, wheat, rye and triticale (rye-wheat).
Plant toxic	Toxic for plants.

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