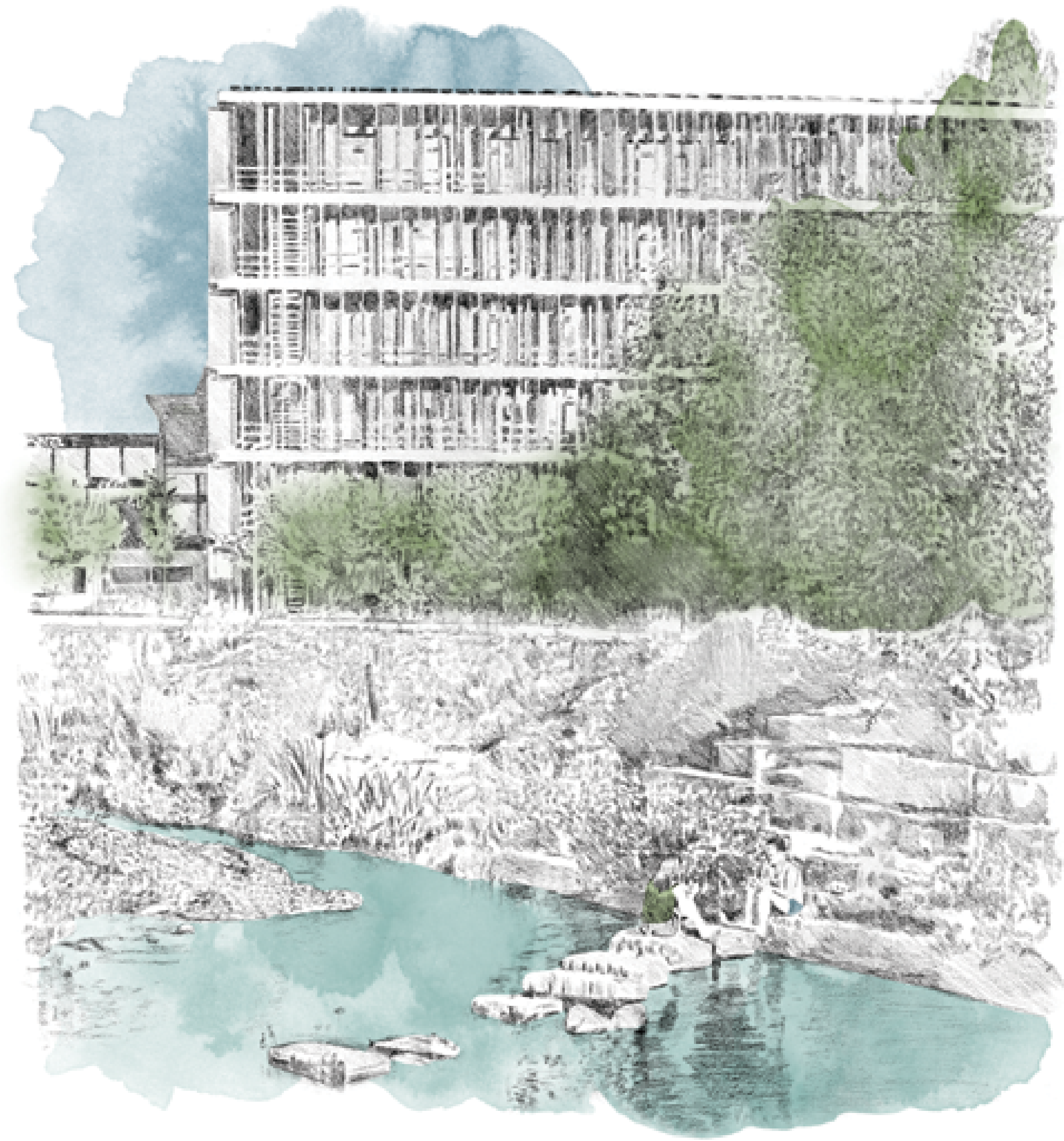
Flows of Science



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Flows of Science

Source Separation Technology at the Swiss Federal Institute of Aquatic Science and Technology (Eawag), 1992-2017.

Luke Keogh

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aquatic research

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Contents

I still recall my first exposure to source separation technology. It was October 2003 and I was visiting Eawag as a member of its external peer review committee. The bathroom on the floor where the committee met was outfitted with a No-Mix toilet, complete with instructions (in German) for the user. I admit that I retreated ignominiously down a flight of stairs to find a "normal" toilet.

I didn't realize it at the time, but in 2003, Eawag was almost half-way through the journey that you will read about in this history. Over that time, much has changed. Ideas have been conceived, challenged and adapted. Colleagues have joined Eawag and developed professionally. Some have stayed and others have moved to take up new opportunities. Some senior colleagues have retired.

Although I came to Eawag's source separation journey late, I have been pleased, over the last 12 years, to support the colleagues who are doing this important work. This history shows Eawag at its best—providing a research environment that allows our colleagues to take risks, recover from mistakes and build professional relationships and personal friendships.

I enjoyed watching this process unfold and I hope that you will enjoy reading about it. This history is a tribute to the engagement of generations of colleagues who were and are determined to contribute to the sustainable well-being of all people.

By Janet Hering, Director, Eawag

Introduction

Good science takes time and teamwork. The birth of new technologies, historians will tell you, never happens in an "aha" moment. It needs time for ideas to develop, time to build capacity, and time to find the right path. And good science also needs the right space to prosper. These days it is a myth that there is one leading figure, often male, coming up with a great invention. There are teams pursuing a problem and finding solutions: professors and students, technicians and managers, administrators and cleaners. In a world too often bent on quantifying good science by citation numbers and attaching arbitrary economic values to research, time and teamwork fall by the roadside. They are hard figures to quantify. But not to the historian. Intrinsic to the art of history is the knowledge that processes unfold over *time*.

The Swiss Federal Institute of Aquatic Science and Technology (Eawag) is one of the world's most highly regarded water research organisations. Born in 1936 as the "ETH Advisory Centre for Wastewater Treatment and Drinking Water Supply", it began with only three scientists—a biologist, a chemist, and an engineer. Today, there are more than 300 scientists. Eawag has a long and storied history. For more than 75 years, its pioneering work has had positive impacts on the Swiss water sector.

In the early 1990s the agriculture and sanitation sectors faced major challenges. Humanity was facing up to the sober reality that our influence on earth systems was having irreversible impacts. There was a fear of a future lack of phosphorous for agriculture; in Africa there was limited access to sanitation and clean water; and in an increasingly urbanised world, waste management infrastructure was becoming overloaded leading to algal blooms and toxic ammonium build-up in water bodies. Many of these challenges still face us today. More nitrogen fertiliser is applied in agriculture than is fixed naturally in all terrestrial ecosystems. Still today, more than 1.8 million people die each year for lack of clean sanitation. Wastewater management infrastructure has become even more expensive, even more cumbersome, and increasingly energy intensive.

It is against this backdrop that many of Eawag's pioneering technologies have been created. In recent years the Blue Diversion Toilet has been one of Eawag's most visible products. At first glance it is a simple reinvention of the toilet so that it operates off-the-grid. There are 2.3 billion people worldwide that still do not have basic sanitation facilities, like a toilet or latrine. The Blue Diversion has the potential of saving millions of lives in middle or low income countries. As this report shows, Blue Diversion was not created in a vacuum. It is a consolidation of nearly three decades of research and capacity building. And inside it merge many strands of Eawag's talents and technologies. There are the best minds from process engineering and social science working together; and, there are technologies like urine separation and gravity-driven membrane filtration functioning in one system. Blue Diversion is the product of a research agenda pursued by dozens of Eawag scientists over decades. Collectively many different scientists have worked together to re-imagine sustainable urban wastewater management.

Technically, scientists at Eawag label these "Source Separation Technologies". In short, the technology attempts to capture resources at the source by separating feces, urine and used water before they are mixed together and piped away. Logically, scientists ask, if urine and feces are not mixed inside the body, why should our waste recovery systems mix them? In fact, 80% of the nitrogen and 50% of the phosphorus compounds contained in wastewater come from urine. These two valuable nutrients and others can be used as fertilisers, replacing energy intensive nitrogen fixation or expensive phosphorus mining. Source separation is a broad term for a suite of technologies that offer alternatives to the current sewer based wastewater treatment system.

Flows of Science charts the history of source separation technology at Eawag from 1992 to 2017. The report proceeds in six parts. Chapter 1 details the influence of sustainable development on Eawag and how this idea influenced the uptake of source separation. Chapter 2 discusses the major cross-cutting project Novaquatis, which was Eawag's first source separation project. Chapters 3 and 4 detail the research and capacity building that flowed after this major project. Here we see that source separation did not travel throughout Switzerland, but went to Nepal, South Africa and Kenya. Chapter 5 charts how these projects influenced the development and success of the Blue Diversion project. Chapter 6 concludes the report with exciting new ventures like the Water Hub at NEST and the Vuna Ltd. Today, source separation has arrived back in Switzerland and is on the cusp of offering major commercial and industrial contributions to the nation.

As this is living history, within the last twenty-five years, the report uses an oral history method. Compiled from interviews with scientists and focus groups and nearly 30 hours of recording it is an intimate story of scientists at work. Scientists have stories to tell and this report captures some of those. Most apparent in the history of source separation at Eawag is that science took time and teamwork. Placing value on these two attributes, as *Flows of Science* shows, is a fundamental part of judging scientific practice.

Timeline. Source Separation Technology at Eawag, 1992-2018

1992

Sustainable Development emerges as a major global principle at the United Nations Conference on Environment and Development, Rio de Janeiro.

1994

Discussions of Sustainable Development and Urban Water Management begin at Eawag.

1995

NoMix toilets developed in Sweden.

Eawag's Department of Sanitation, Water and Solid Waste for Development (Sandec) is established as a successor to the International Reference Centre for Waste Disposal (IRCWD).

1996

The article "Separate management of anthropogenic nutrient solutions (human urine)" by Larsen and Gujer is published in *Water, Science & Technology*.

Eawag awards internal funding for Udert's doctoral research on urine separation.

1997

Water, Science & Technology releases a special issue on urban water management with a focus on source separation technologies.

2001

Novaquatis, a transdisciplinary project on urine source separation, begins (ends in 2006).

2005

Decision to install source separating toilets in the new Forum Chriesbach building.

2007

Eawag Info Day focuses on urine source separation as the closing event for Novaquatis.

Establishment of the Sustainable Sanitation Alliance (SuSanA) with Sandec as a founding member.

Eawag Partnership Program (EPP) begins with the Head of Sandec as EPP Chair.

2008

Publication of the *Compendium of Sanitation Systems and Technologies* by Tilley et al.

STUN project to recover nutrients from urine in Nepal begins (ends in 2010).

Larsen and Lienert win Swiss Academies Award for Transdisciplinary Research for the Novaquatis project.

2009

Empa constructs the "Self", a standalone apartment living space that incorporates Eawag's source separation technologies.

Empa and Eawag propose a combined research platform and guest house (a precursor to NEST) to the Board of the ETH Domain.

2010

In Durban, South Africa, the VUNA project begins as a collaboration between Eawag and eThekwini municipality with funding from the Bill & Melinda Gates Foundation (ends 2015).

Eawag's first paper on Gravity Driven Membrane (GDM), "Stabilisation of flux during dead-end ultra-low pressure ultrafiltration" by Peter-Varbanets et al., is published in *Water Research*.

SAFIR project employing GDM for drinking water treatment begins.

2011

Eawag invited by the Bill & Melinda Gates Foundation to take part in the Reinvent the Toilet Challenge.

Sandec receives the IWA Development Solutions Award for Science.

Blue Diversion toilet project begins (first and second phases of the project run until 2014).

First large-scale urine nitrification reactor built in Switzerland.

2013

Publication of the book *Source Separation and Decentralization for Wastewater Management* (IWA Publishing) edited by Larsen, Udert and Lienert.

2014

Second edition of the *Compendium* published.

BioBurn technology taken to Kampala, Uganda, in SEEK project.

Blue Diversion receives IWA Project Innovation Award.

2015

United Nations Sustainable Development Goals adopted, including Goal 6: Water and Sanitation.

Blue Diversion Autarky project begins.

Wings project begins with discretionary funding from the Eawag Directorate.

Eawag and its start-up company Vuna Ltd. collaborate to produce fertiliser from urine collected at OLMA, Switzerland's largest agricultural fair.

Vuna Ltd. established and begins commercial production of fertiliser from urine.

2016

The NEST building, constructed by Empa, opens with water and wastewater managed by Eawag's Water Hub.

2018

Aurin, Vuna's fertiliser from urine, is granted a Swiss license for use on all plants including edible crops, the first such approval world-wide for a urine-derived product to obtain such an approval.

Chapter 1

Resources

Achievements

- ~Eawag takes on the challenge of Sustainable Development as a new environmental paradigm.
- ~Scientists at Eawag consider urine source separation as a radical approach to urban water management.
- ~In 1996, Tove Larsen and Willi Gujer publish the first Eawag article on Source Separation Technology.

Three Beginnings

Thinking about source separation began at Eawag in 1992. Three separate events happened that allowed source separation to be considered an important technology. First, the United Nations Conference on Environment and Development was held in Rio de Janeiro and firmly established sustainable development as the transformational paradigm of the decade. Second, Alexander Zehnder took over as Director of Eawag. Third, Tove Larsen joined ETH Zürich as a post-doctoral environmental engineer. These three moments came together in the early 1990s and enabled source separation to emerge at Eawag.

Sustainable development encouraged people to radically rethink economic development and to find new ways to stop the destruction of natural resources and pollution on the planet and the impact this would have on future generations. The Earth Summit at Rio, as the 1992 United Nations conference came to be known, was a pivotal moment in global environmental politics. From it came the United Nations Framework Convention on Climate Change, the United Nations Convention on Biological Diversity and Agenda 21. The latter was an "action plan" for the United Nations on sustainable development. It was a major event for both the political sphere and civil society—there was an enormous turnout of NGOs at Rio. The Earth Summit, and the Brundtland Report before it, were moments when sustainable development began to be accepted at the institutional level as a guiding environmental idea.

If sustainable development drove people to rethink the human-environment relationship, then the Director of Eawag, Alexander Zehnder, encouraged everyone to consider the importance of the concept for water management in Switzerland. Every year Eawag hosts an "Info Day", a day where their best and most innovative science is discussed and promoted. At the 1993 Info Day, Zehnder shocked the audience by telling them that in thirty-years time consumption of key resources in Switzerland should be reduced by two-thirds without any reduction in the standard of living. Resource consumption was a key point of concern. As Zehnder wrote in the 1994 edition of Eawag News, "We cannot put resources in a museum. We have to learn to harness them in such a way that they are still there for us and our descendants."

In Dübendorf, the winter semester of 1994-95 was dedicated to sustainability. There were scientists from physics, chemistry, biology, human ecology, municipal wastewater engineering, cybernetics and art, all discussing and debating the concept. With sustainable development on his mind, Zehnder was daring enough to encourage everyone at Eawag to think about the next cross-cutting innovative water project.

Eawag is well known for its foresight. It is common to hear from Eawag scientists, that they don't work on the problems of today, but rather on the water problems that Switzerland will face in twenty years' time. Zehnder wanted an interdisciplinary sustainable development project that would bring many of Eawag's departments together to work on a problem of practical relevance.

Born and educated in Denmark, Tove Larsen arrived in Switzerland to take up a post-doctoral position with the Chair of Urban Water Management at ETH Zürich. The newly elected professor, Willi Gujer, was at that time Head of the *page 7:* Water pumping station, industrial interior and pipes. Photo Shutterstock.

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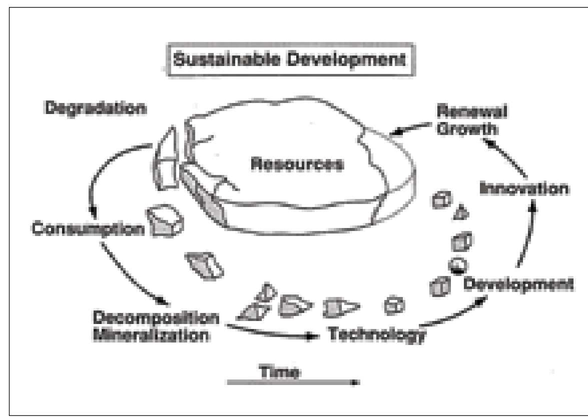
"Sustainable Development as a steady state over time." Appeared in Alexander Zehnder's article in *Eawag News* 1994, 4.



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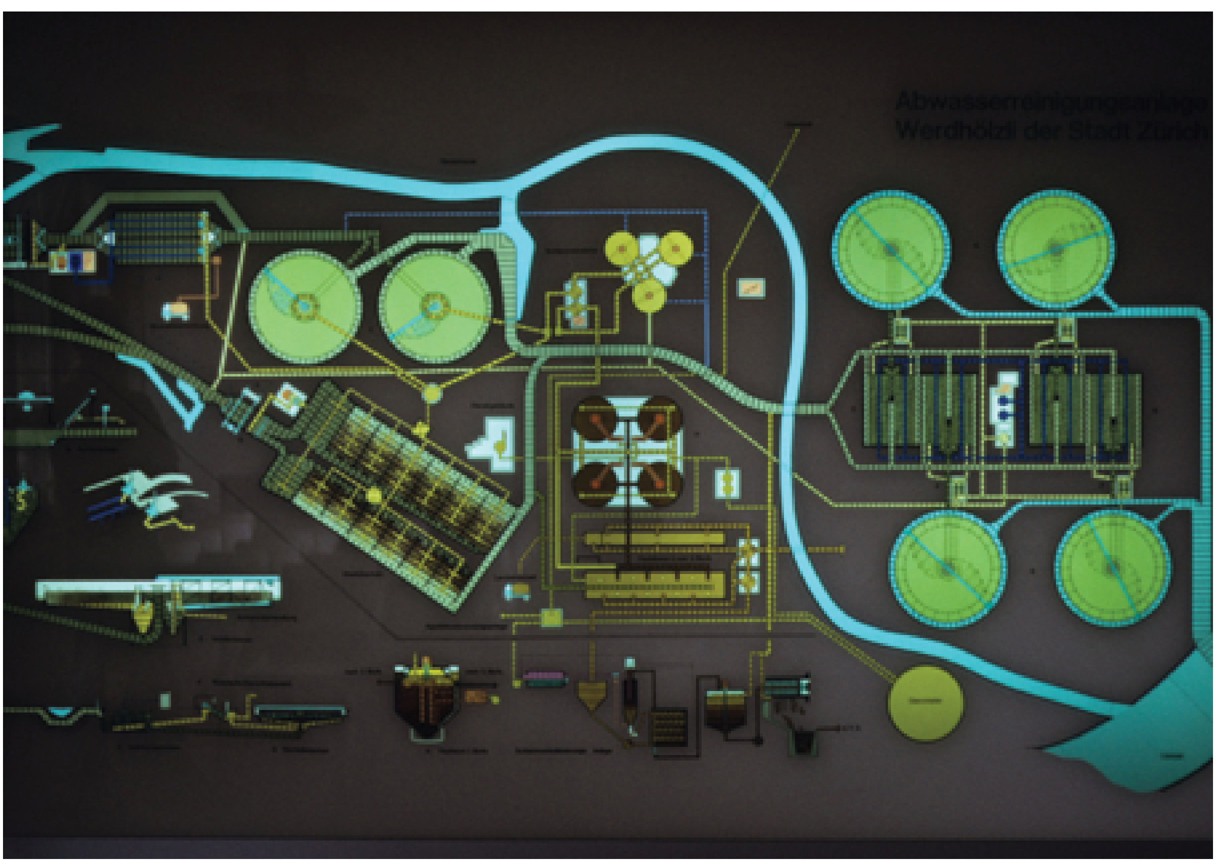
Schematic of the Werdhölzli wastewater treatment plant, 1973.



Eawag Engineering Department and employed a small group at ETH Zürich to support his teaching obligations. Larsen joined the teaching assistants and led the tutorial activities for the students. With no research activity on urban water management at ETH Zürich, the Engineering Department at Eawag was where many engineers, including Larsen, looked for research collaboration.

Inspired by the Brundtland report and the Rio Declaration, Larsen decided to build her career in the area of sustainable urban water management. Using the close relationship with Eawag, she set up a discussion group on the topic. This captured the interest of many scientists at Eawag, including Rik Eggen, Willi Gujer and Max Maurer. It rapidly became clear that the Rio Declaration, and other reports on the topic, were too vague to form the base of a sustainable change of wastewater management. This led Larsen and her colleagues to explore deeper questions on the topic: what might sustainable urban water management look like? This question led to another question: how might we disrupt the current system we have?

Miasma: a brief history

To understand the urban water system that the small group at Eawag were trying to disrupt we must first understand the system that they were working with. To understand urban water management in most developed countries we must look back two centuries to smelly London and Paris.

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Research at Eawag, Dübendorf. Showing Claude Jaques, measuring fog and dew in 1983.

←
Early research at Eawag Kastanienbaum, 1913.

→
Alexander Zehnder, Eawag, Director, c1993.

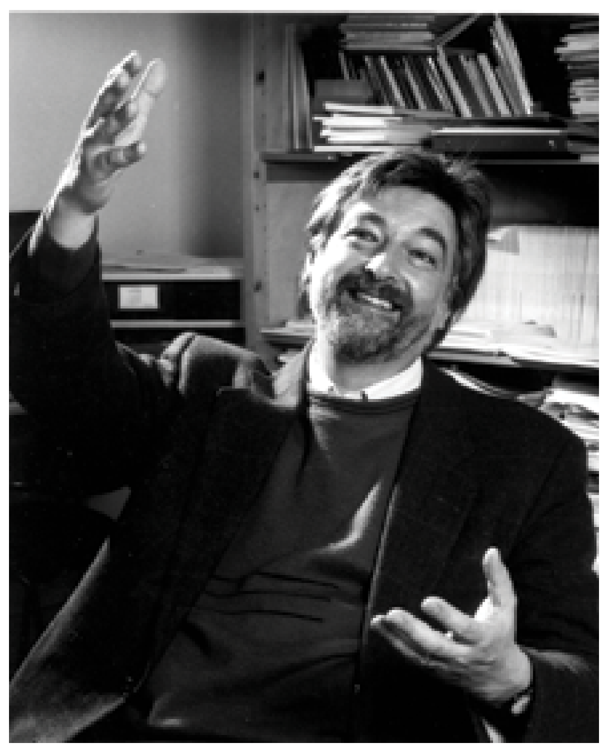
In the eighteenth and nineteenth century, cities like London and Paris stank. Human waste carries many undesirables. The most immediate is smell (miasma) but the most crippling is disease.

As global populations grew dramatically in the eighteenth and nineteenth centuries diseases spread. Populations were hit hard by infectious diseases: smallpox, malaria, yellow fever, cholera, typhoid, typhus, tuberculosis, scarlet fever, measles, mumps, and diarrhoeal disorders. Many of these diseases were not necessarily caused by human waste but rather appalling living conditions. Public health was a major issue for governments. By extension, a city's health, its cleanliness and its wellbeing became tied up with providing clean drinking water and removing waste. Securing water was always the first order of the day. Most often this was done through a community-wide-system of pipes. It was often many decades after drinking water was supplied that a centralised sanitation system was commissioned.

The centralised wastewater system started out as the "sanitary idea" and was a major public health movement in European cities. At its heart was the idea that health depended on sanitation and that the physical environment had a major influence upon the individual. Much work was done in London slums, especially after the cholera epidemics of the 1830s, to understand the problems facing the city. The people who promoted the sanitary idea argued for the environmental aspects of hygiene and therefore promoted a large-scale city-wide approach to sanitation. At the same time the "Water Closet" (toilet) became a widespread technology for middle-class homes. While this was a more convenient method of disposing human waste, it also increased the use of water and overloaded cesspools. The wastewater from overloaded cesspools could then not percolate into the soil and overflowed.

The city-wide system of sanitation became the technological solution. In short, clean water was piped into the home and waste was piped out into the sewer. Water was used to make the waste flow. It was an industrial-scale public works project. One of the leading advocates in London, James Chadwick, envisioned that the sewage would flow out of the city to become agricultural fertiliser, much as it was when night soil had been repurposed in places like Paris. Ultimately, however, sewage was discharged into rivers and watercourses and led to other problems, such as nutrient overloading in rivers and lakes.

The centralised treatment system came next. In the early twentieth century, big engineering solutions to wastewater management became the norm. Instead of letting sewage drain into rivers and waterways, central canals were first used and then "sewage farms" and finally specialised wastewater treatment plants were developed. At the same time, interest developed in sewage treatment as a biological process, beginning with Edward Arden and William Lockett's activated sludge approach. This provided the basis for centralised treatment to convert sewage into treated effluent.



The “sanitary revolution” transformed cities. It made them cleaner and healthier, allowed for more people to live in them. At the same time the system of pipes, sewers and tunnels shaped the very structure of the cities we now inhabit. In a 2007 survey by the *British Medical Journal*, more than 11,000 readers, chose the sanitary revolution as the most important medical milestone since 1840—more important than antibiotics or the development of anesthesia.

The “sanitary revolution” transformed cities, making them cleaner and healthier and allowing more people to live in them. As populations grew, wastewater treatment plants also needed to grow in size to cope with more sewage. And with increased size came increased energy inputs to operate the plants. The modern system of wastewater treatment, as scientists at Eawag will tell you, is largely a transport system. By the 1970s, infrastructure was ageing and there was talk in many countries of “infrastructure crisis”. Today, about ninety percent of all investments into wastewater treatment goes into pipes. The technological solution of wastewater infrastructure and treatment had solved an important public health problem but had created other problems too. Even in countries that have successful practices, like Switzerland, the urban wastewater management system is resource intensive and costly.

Source Separation Emerges

For Eawag scientists in the early 1990s, the existing system of wastewater treatment worked, but it could do better. There were many areas for concern: large amounts of fresh water was needed to flush sewers; phosphorus used to fertilise our foods was a non-renewable resource; increasing populations meant that urban infrastructure could not keep pace with growing populations, indeed in many low-income countries it would be impossible to even implement such a system.

Talk, the saying goes, is cheap. But not at Eawag. Meeting with colleagues and deeply thinking through a problem is how they do things. Discussions might last for months, or even years, until a pathway for research opens. At Eawag they approached the topic of sustainable urban management simply by asking: what was the smallest thing that could be done with the biggest influence on urban water management? The discussions were informal but regular. They happened every third week. They were not high intensity, rather curiosity driven. At the meetings, there were scientists from many backgrounds. And the meetings went on in this way for nearly two years.

At one of the meetings someone just said, “what about urine separation?” It was not Larsen who said it, but Larsen saw it as an opportunity. As another Eawag scientist describes the moment: “it was really just a crazy idea that doing something radical could really provide some benefits.” Separating urine from the waste stream flowing down sewers into wastewater treatment plants was the small intervention that they were looking for.

Mixing urine in with feces and water and then flushing it down into the sewer at first appears unproblematic – it accounts for only 1% of the total volume of wastewater. But looking closer, urine accounts for about 80% of the nitrogen and 50% of the phosphorus. To handle these loads, wastewater treatment plants must be enormous and employ substantially more processes to remove nutrients.

We consume an organic rich diet that is largely made up of the chemical elements carbon, nitrogen, phosphorus, and potassium. While much of the carbon is exhaled as carbon dioxide (CO_2) when we breathe, the remaining nutrients are water-soluble and come out of the body as waste—urine and feces. Although it smells, it is filled with many valuable nutrients. Urine is easier to handle and has a relatively higher amount of nutrients. Feces, while valuable, also carry most of the pathogens and are more dangerous.

Eawag was not the first to consider source separation. The Swedes had a tradition of urine separation, especially in their summer huts. In the early 1990s, source separation projects gathered momentum, with particular interest from researchers at the Swedish University of Agricultural Sciences and others around Uppsala, researchers at Lulea Technical University, and at Gothenburg University. Unknown to Eawag researchers, their Swedish colleagues were developing research programs on urine separation.

By the mid-1990s there were many pilot projects underway and urine separating toilets were installed in apartments and in small towns. But Sweden, some say, went to the field too early. There were too many problems for users and satisfaction dropped accordingly.

Looking further back, one will see that valuing human waste, as a resource, is as old as human ingenuity. Throughout history, many cultures around the world used human waste as a resource. Using human excreta as an agricultural fertiliser in China dates back possibly three thousand years to the Shang Dynasty. It took off as an important resource when China switched from a crop/fallow rotation to a crop/crop rotation a little over two thousand years ago. The ancient Chinese even distilled their excreta into a fertiliser the same way they distilled their wine. Using human waste as a fertiliser has continued throughout much of China's history. And the Chinese were certainly not alone.

The Romans used source-separated urine widely. They used it in agriculture, horticulture, veterinary uses and for cleaning clothes (fulling). Using urine as a resource has persisted until very recently. In Paris, nightsoil was recovered and turned into *poudrette* a powdery fertiliser that was prized by farmers. Although horse manure was the most used urban fertiliser in the city, recovered human waste was still a highly valued fertiliser right up until the First World War.

Flows of Urine

In the beginning of urine source separation no one wanted to refer to "urine", so they called it Anthropogenic Nutrient Solution (ANS). The acronym did not last long. But once scientists attached a value to it, it was no longer a smelly human by-product, it was a resource. By 1996, Tove Larsen and Willi Gujer had prepared a number of articles on the potential of urine source separation. The first article published by Eawag on the topic was titled, "Separate management of anthropogenic nutrient solution (human urine)" and appeared in the journal *Water, Science & Technology* in 1996.

At the time, Willi Gujer was one of the world's leading experts on conventional wastewater treatment. In the mid-1990s he wrote "the bible"—*Siedlungswasserwirtschaft* (1998)—on wastewater treatment in Switzerland and was highly regarded in the field. But when he threw his support behind source separation, it seemed that most people weren't interested. In 1996, he attended the IWA conference in Singapore and presented the idea. He was given a small room in the back edges of the conference, few people attended apart from his colleagues who felt obliged to listen to their friend. No one appeared interested in urine source separation.

The timing of writing and publishing is sometimes unclear. A first article on the principles of sustainable urban water management was submitted to the journal *Water Research* around 1994. It was rejected for not being a technical paper, but led to a discussion amongst the publishers and finally to the decision to set up a call for a special issue of *Water, Science & Technology* on sustainable urban water management. The original paper was finally published in 1997 by Larsen and Gujer under the title "The concept of sustainable urban water management". The paper was one of the earliest in urban water management to engage with topics such as the circular economy. The paper also set up the hypothesis that source separation would allow for more resource-efficient wastewater treatment.

In this special issue of *Water, Science & Technology* there were four articles on source separation technology. For this issue, the editors did not write the usual editorial but rather reprinted the famous William Blake poem "Tyger, Tyger". And as an editorial, one of the editors Mogens Henze added his own lyrical contribution to the end of the poem: "Once the tiger was a dangerous animal,/ now it is endangered./ Once water was a dangerous resource,/ now it is endangered." Such a creative flutter would not be possible for scientists today. But in the 1990s there was an energy that sustainable development created among scientists. This fervor was not lost on Eawag scientists. They questioned the existing wastewater treatment system and one of the potential solutions they came up with was source separation technology.

One researcher, Bernhard Truffer (now Head of Eawag's Department of Environmental Social Sciences), was heavily involved in sustainable development throughout the early 1990s. Although not directly involved with source separation, his field of research in "transformations" allowed him to observe what happened at Eawag. With great insight, Truffer reflects,

> "I would give credit to Willi Gujer and Tove Larsen to have been intellectually courageous ... They kept up and worked on it for 25 years now. It takes a long breath to work on this fundamental questioning. In that sense, I would say it is a very honorable and bold intellectual strategy that they developed and saw through. That is what you always see in these fundamental transformations. In the beginning the alternatives are always ridiculous ... [In my field] they are called hopeful monstrosities ... we know that it takes about 20-30 years for these things to change." ▪

page 13: The Silent Highwayman. The heavily polluted Thames in the nineteenth century warranted this cartoon in *Punch* 10 July 1858.

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Werdhölzli, 1973. The biggest investment in urban water management is in pipes; source separation technologies challenges this thinking.

→
A typical Swiss wastewater treatment plant, 1972.

Chapter 2

Capacity

Achievements

- ~Kai Udert completes his doctoral dissertation on urine source separation.
- ~Novaquatis (2001-2006), a major transdisciplinary research project on source separation technology (SST), is completed to great success.
- ~NoMix Toilets installed in Forum Chriesbach, 2006.

Stabilising an Idea

Although urine source separation seemed a radical idea for the wider engineering community, it was welcomed at Eawag. In 1996, internal funding was made available for a project on urine separation. It was fortunate that the Eawag Directorate was so open to the concept. It was so outside of the mainstream that larger national funding bodies might never have funded the research. With internal funding, Tove Larsen was able to bring Kai Udert, a cautious but brilliant process engineer, to Dübendorf.

Turning urine into fertiliser was something that scientists had not really tried before. Udert's doctoral research was the first step. When Udert commenced his research there was one very practical question that needed to be answered—where to get urine? As soon as urine went into the sewer it became so diluted that it was not useful for testing or producing fertiliser. He tried to get urine from the Ökozentrum Schattweid in central Switzerland, where a diverting toilet was used for dry sanitation but this was too cumbersome on the long term. He tried many different places but could not find a solution.

Finally he realised that he needed to collect urine in Dübendorf. But it took a long time. There were discussions about where the toilet should be put, who should use it, and even about how to clean the toilet. In 1998, a Swedish NoMix toilet was installed in Eawag's laboratory building. Trying to negotiate these challenges and the resistance to installing just one toilet gave Udert a glimpse of what it meant. "You realise it is a system change", he reflected on those early challenges.

Along the way, the researchers also took on their first consulting jobs. Geberit, the major Swiss company for flushing and piping systems, had a problem with clogging urinals. They found out about the research at Eawag and contracted Udert and Larsen to solve the problem. They worked on three case studies in airport urinals.


page 17: Aerial view of solid contact clarifier tank sludge recirculation. This conventional approach was challenged in the transdisciplinary project Novaquatis. Photo Shutterstock.

←

The first NoMix toilet installed at Eawag (far left).;

Clogged pipe from urine precipitates. Photos Kai Udert, Eawag.

Precipitation build-up is a major problem when working with urine. They were able to explain Geberit's problems and along the way made an important industry partner for their research. This work also helped Udert to refine his doctoral research question.

Udert's dissertation, completed in 2002, both proved the potential of source separation and solved some very practical problems. In the lab, Udert was able to stabilise urine using the nitrification process; this was an important early step towards the ultimate goal of producing fertiliser from urine. He was also able to explain the causes of pipe clogging. Through much trial and error he showed that citric acid was a simple solution for cleaning precipitates from pipes.

From Lab to Practice

Since the Rio Earth Summit, the Directorate at Eawag had been in search of a major cross-cutting research project on sustainability. In the late 1990s, Bernhard Truffer led a project on green hydropower based in Kastanienbaum, another of Eawag's campuses located near Lucerne. Finally in 1999, after seven years of discussion and a few pilot projects and publications, the Directorate had a concept that was both practically orientated and transdisciplinary—urine source separation.

Eawag invested heavily—more than one million Swiss Francs over five years. Urine source separation was much more than just a practical intervention into the existing system. It was about the value of resources; it was about enacting small-scale practices to affect major systemic change; it was about taking a highly complex technological system– urban water management—and making it more sustainable. The Novaquatis project (2000-2006) was born.

Novaquatis explored the potential of urine source separation as an alternative wastewater treatment. Novaquatis was about improving water pollution control by reducing nutrient and micropollutant inputs and about recovering resources to close the nutrient cycle. The project team used NoMix toilets, invented in Sweden, to test the science and acceptance of this potential technology. The project was structured around nine work packages that were organised around stages of the nutrient cycle. Billed as a cross-cutting project there were at least 40 scientists involved, coming from fields as diverse as sociology, economics, natural sciences and engineering. Among the key questions that these work packages considered were: Would people accept NoMix toilets? How to remove unwanted pharmaceuticals from urine? Could urine be stabilised to form a valuable fertiliser? How to apply these insights?

Heading the project was Tove Larsen, she was later joined by Judit Lienert. It turned out that Larsen and Lienert had very complementary skills and traits, which carried the project to its successful completion. There were also other key scientists involved in steering the project, including Rik Eggen and Max Maurer.

Kai Udert, by this time half-way through his doctoral research, was often called upon for practical advice. This is the nature of Eawag. No matter what the project, you know if you have a question that another colleague can help you with then you just knock on their door and ask them for advice. As Udert says, "I think it's really common at Eawag that you do it this way. It should be this way anyway but it's not everywhere." This ability to build upon previous research, to look for help from colleagues and to work together, continues today.

The transdisciplinary nature of Novaquatis also meant that it was more than scientists that needed to be managed. From very early on they had secured public partners on the project. The Canton Basel-Landschaft showed a keen interest and had NoMix toilets installed at a public library. NoMix toilets were also installed in an apartment, at a vocational college and more were installed at Eawag in Dübendorf. Farmers and consumers were also consulted about the potential of using urine as a fertiliser.

Given the unique topic being researched, the media was also very interested in the progress of the project. This increased expectations. It also made the project team be more reflective. They asked themselves, "what would society expect of us when we finished the project?" But there was also a very practical expectation of users. They were prepared to use a toilet that was a little different if they knew it was being used to create something useful. So acceptance was tied in with the effectiveness of the technology.

Novaquatis tested the possibility for implementing NoMix technology on a wide-scale. It tested both science and people. Before Novaquatis urine source separation was largely just an idea without rigorous science. First and foremost among their fundamental scientific questions, could urine be stabilised to form a valuable fertiliser? Flowing from that they asked important questions on the processing of pharmaceuticals and on the available methods to stabilise urine. On the social aspect it was very important to unearth what people actually would do with this technology. Covering this wide spectrum from engineering to social sciences Novaquatis was ambitious and wide-reaching.

One of the unique approaches of Novaquatis was to engage all stakeholders in the project. From the outset engaging the staff at Facilities Management proved vitally important. Udert was able to tell cleaners how to properly flush the toilets with citric acid once per month to avoid blocking. And so too was Lienert in constant contact with Facilities Management regarding the upkeep of the toilets. Other institutes implementing source separating toilets did not have such foresight. For example, the German Society for International Cooperation removed all of their urine diverting toilets in their main offices after only a few short

↑
Children were an important user group tested in Novaquatis.

→
Kai Udert showing how a NoMix urine diverting toilet works, 2006.

↓
Facilities management cleaning the NoMix Toilet.

Photos Ruedi Keller, Eawag

years because of blockages. By engaging the full range of stakeholders Eawag was able to avoid such mistakes that other research organisations faced.

Closing the Cycle, Making it Flow

Novaquatis was a major success. It produced 47 scientific papers, it showed source separation technology as an important potential tool for wastewater treatment, and it showed Eawag's unique ability to complete major cross-cutting projects. In recognition of the projects wide-scope Tove Larsen and Judit Lienert were awarded the 2008 Award for Transdisciplinary Research from the Swiss Academies. To go into the full details on the scientific results of Novaquatis is unnecessary. These are very accessible in the final report *NoMix: A New Approach to Urban Water Management* (2007) and in *Eawag News* (2007), both available online (listed in the Sources).

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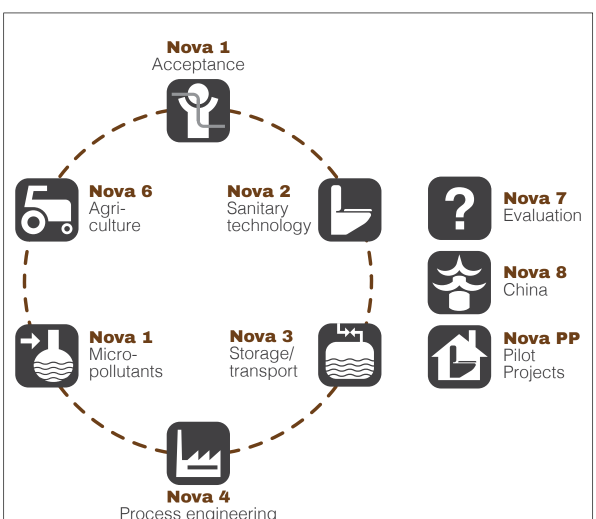
The nine "work packages" of the Novaquatis project.



If Novaquatis had ended with the funding cycle, much like research projects at universities, then it would have still been a success. But with hindsight Novaquatis's value lies in something much more fundamental and uniquely afforded at an institute like Eawag. As we will learn in the coming chapters, they were able to make it flow into other high impact outputs. There are three important effects.

First, the scientific contribution. This is not necessarily unique to Eawag, but it did have important flow-on effects. In one part of the research scientists were able to show that fertiliser could be produced from urine through a process of electrodialysis—they called the product urevit. Some parts of the process remained unstable but they were able to remove the pharmaceuticals from the urine. By testing many approaches to urine processing the engineers had shown it was possible to produce a viable product. However, there still remained much work to go from lab to marketable product.

Second, Novaquatis developed Eawag's capacity in the field of source separation. Many of the scientists that were employed for Novaquatis stayed at Eawag and went on to have a big impact in other areas of the institute. People like Wouter Pronk, who started at Eawag working on the electrodialysis project, went on to work on membrane technology. Judit Lienert, who so capably managed the project, had started small projects combining natural science and social science in the field of multi-criteria decision analysis. In the wake of Novaquatis she moved more seriously into this field and is now one of the leading Swiss experts on the topic and teaches a yearly course at ETH Zürich. Through the visibility of the project young researchers around the world were drawn to Eawag to work on source separation. One of them was the young, ambitious Canadian, Elizabeth (Liz) Tilley, who continued working at Eawag after Novaquatis ended. Another was Mariska Ronteltap from the Netherlands, who now lectures at IHE Delft in the Netherlands, teaching students from all over the world about source separation. One of the great hidden values of Novaquatis was in building the capacity of the institute.

Third, Novaquatis was not an easy project. Dealing with so many scientists and so many different interests was tiring work. It was an important learning outcome for Eawag. As one scientist explained the end of Novaquatis: "you take somebody who was a good scientist and then all of a sudden they have to be a project manager. This is one of the problems that we are trying to learn from. When you do it the second time it works much much better. This is one of the things we took out of Novaquatis that project management is key and difficult work." It takes a capable and skilled manager to put all the disciplines together for effective research outcomes. The experience in Novaquatis ably prepared Larsen for her next major trans-disciplinary project – Blue Diversion (Chapter 5). Eawag is still learning from this experience: an experienced research manager is overseeing the new strategic program on non-grid solutions, Wings. Even with these challenges Novaquatis still produced much valuable synthesis work. Among many publications, Larsen, Lienert and Udert edited the book *Source Separation and Decentralization for Wastewater Managemen*t (2013).

Building Capacity

Another outcome that proved to be important came at the end of Novaquatis. In 2005, Eawag commenced construction on a brand new main building: Forum Chriesbach. This highly advanced building was energy and water efficient and constructed with environmentally friendly materials. Based on the success of the Novaquatis project, urine separating toilets were installed. The urine was stored in tanks in the basement of the building. At the time there was no capacity in place to treat the urine so it was allowed to drain to the sewer. It would take another six years before they developed the technology to treat the urine. But they were prepared. And, as Larsen puts it, "People believe us much more because we are using the toilets"

With all the effort of Novaquatis, urine source separation had entered the vocabulary of engineers; yet it still remained at the periphery. In a 2009 paper, Larsen, Maurer and Lienert, described the potential but lack of will:

> "So long as no one invests in source separating technologies, such stay low-tech and are at best produced locally in small numbers, there being no market. We are convinced that this vicious circle can and should be broken. If we want to, it is possible to develop on-site source separating technologies that are just as reliable and easy to maintain as any modern household espresso—and just as affordable."

Novaquatis was the culmination of more than a decade of work in developing source separation at Eawag. But the next phase of its story took a much more surprising turn. Although there were some small pilot projects on China, Novaquatis was largely focused on Switzerland and industrialised countries. The next real leap forward would happen as their ideas travelled to developing countries. ▪

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Forum Chriesbach under construction, completed in 2006. Photos Eawag; lower image Stefan Kubli, Eawag.

Chapter 3

Development

Achievements

- Sandec publishes *Compendium of Sanitation Systems and Technologies* (2008).
- STUN is completed as Sandec's first dedicated source separation technology project.

Real-World Problems

Walk around Eawag today and ask any process engineer, "do the problems you are working on make a difference?" Chances are they will answer, "yes, we are solving real world problems. We are helping change the world." This was not always the case.

Janet Hering started as Eawag Director in 2007. One of her first tasks was to chair the 2007 Info Day, which was solely dedicated to urine source separation, in particular the work of Novaquatis. In contrast to Alexander Zehnder's time as Director, Hering's tenure is defined by a much more nuanced approach. Her widespread encouragement of transdisciplinary research has been of real world significance. But one of the great cohesive outcomes of her leadership has been to foster the work of Eawag's Department of Sanitation, Water and Solid Waste for Development (Sandec) as fundamental to the philosophy of the entire institution. Very early on in her tenure she helped to set up the Eawag Partnership Program, a fellowship program where students from developing countries come to Eawag to spend time tapping into Sandec and Eawag's expertise. Now a decade on there are more than 80 alumni spread all over the world.

Sandec is a Research Department at Eawag that focusses on solving sanitation issues in low and middle income countries through applied research. It consists of a small group of experts who are highly motivated by the shared goal to ensure that everyone can realise their right to safe and adequate water and sanitation. Their purpose and drive permeates throughout Eawag.

Sandec's origins date back to 1968 when it was the International Reference Centre for Waste Disposal (IRCWD). It was set-up originally as a WHO Collaborating Centre responsible for disseminating valuable scientific information related to water and sanitation to interested scientists and policy makers in developing countries. In the days before the internet, they served a valuable role in building the knowledge base in developing countries. In 1980, the Directorate felt that Eawag's large scientific and technical knowledge could be used with more intent to tackle problems in developing countries and gave this task to Roland Schertenleib.

For over a decade the small team at IRCWD chipped away completing research projects around the world. In 1995, the IRCWD changed their name to Sandec and solidified their activities as a research department with access to the very best scientists in the world. In the first issue of *Sandec News*, they wrote that "our strength and comparative advantage is our direct access to the comprehensive scientific and technical knowledge within Eawag." They remained a WHO Collaborating Centre, and all their projects were always conducted in partnership with NGOs and scientists on-the-ground.

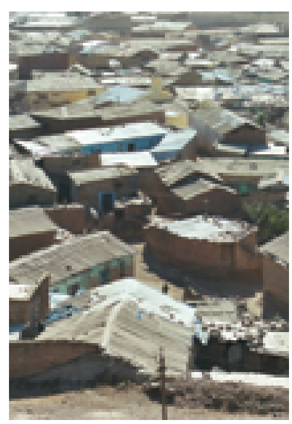
For 25 years Roland Schertenleib was a driving figure within Sandec. Schertenleib has always thought outside of the box and questioned the prescribed scientific knowledge in light of the challenges in developing countries. It was after a fellowship with the World Bank that he became more vocal about the "cookie cutter" model of large-scale development projects. There was a problem with the prescription of the large-scale development projects by some aid organisations. For example, taking a highly complex sanitation system complete with sewer network and wastewater treatment plant to a highly populated city in Africa would probably never work. There were many reasons: the country would never be able to pay back the loan, there was not enough water to flush the sewers, and they would never be able to maintain the system. There had to be other ways.

As Schertenleib tells it, "one thing that I experienced in my field is that people always thought there is one silver bullet". But there is not. It was with this realisation that Sandec's projects put more emphasis on place appropriate on-the-ground solutions. Sandec's vision has always been about implementation in conjunction with the social fabric of a place.

In this way, source separation technology is merely one of many possible approaches. Christoph Lüthi, Head of the Sandec Department, describes it very clearly, "Sandec is not a proponent of source separation technology and we have been respected for this."

Sandec is about finding ways to encourage best practices through applied research. Lüthi goes on, "We always say technology is not the main issue, it is the enabling environment, which is the main issue". The enabling environment, which allows effective technology implementation, is established at the household and community level.

Schertenleib worked closely with colleagues to write the "Bellagio Principles" (2000). These guidelines suggested a household-centred approach to sanitation. It was a radical



page 25: Filling water containers at a local well in Kathmandu, Nepal. Photo Arne Beruldsen, Shutterstock.

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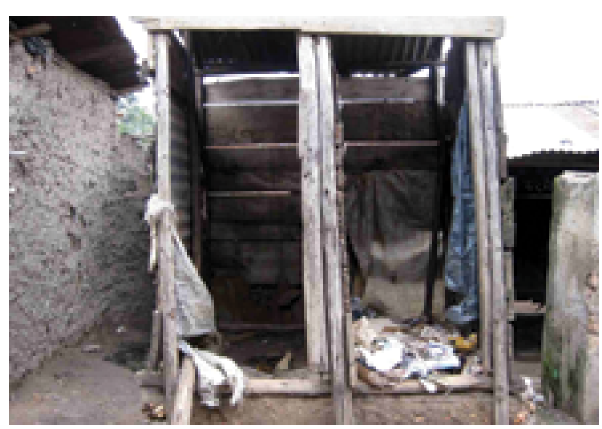
There are many sanitation challenges in low and middle income countries. Photos Eawag. Upper right Christian Zurbrügg, Eawag.



turn away from the large-scale technocratic approaches of development organisations. It was widely adopted. For Christoph Lüthi one of his most important projects soon after joining Eawag was to validate the concept in the "real-world". The ten-step Household Centred Environmental Sanitation Approach (HCES), based on the Bellagio principles were too long and the focus on the household was too narrow. What emerged was CLUES —Community-Led Urban Environmental Sanitation Planning. Since 2011, it has been implemented by NGOs worldwide.

Source separation technology was able to prosper at Eawag when Sandec took it on as one of their approaches to sanitation. Many of the most important projects on source separation between 2007-2015 involved key contributions from Sandec. If we look upon source separation technology as but one of many technologies in Sandec's toolkit, then the evolution of one of their most important publications is better understood.

In 2008, coinciding with the International Year of Sanitation, Sandec published the *Compendium of Sanitation Systems and Technologies*. It was Schertenleib's dream to have in one volume a toolkit of technologies where stakeholders in low and middle income countries could make informed decisions on the most appropriate sanitation for their location. As Schertenleib described, "if we are serious that people should get involved in the decision making then we have to give them the tools. And that is when we said, we need a collection of different technologies." The *Compendium* brought those technologies together.

Liz Tilley, who had come to Eawag to work on Novaquatis, took on the job of writing the *Compendium*. With her engineering background and her skills as a native English speaker, she was able to complete the task in a little over one year. Also working on the project were Lüthi, Schertenleib and Christian (Chris) Zurbrügg. Lüthi, trained originally as an architect, was a visual thinker and insisted that each technology

←
Elizabeth Tilley, presenting her research on incentive schemes at a conference. Photo Max Maurer, Eawag.

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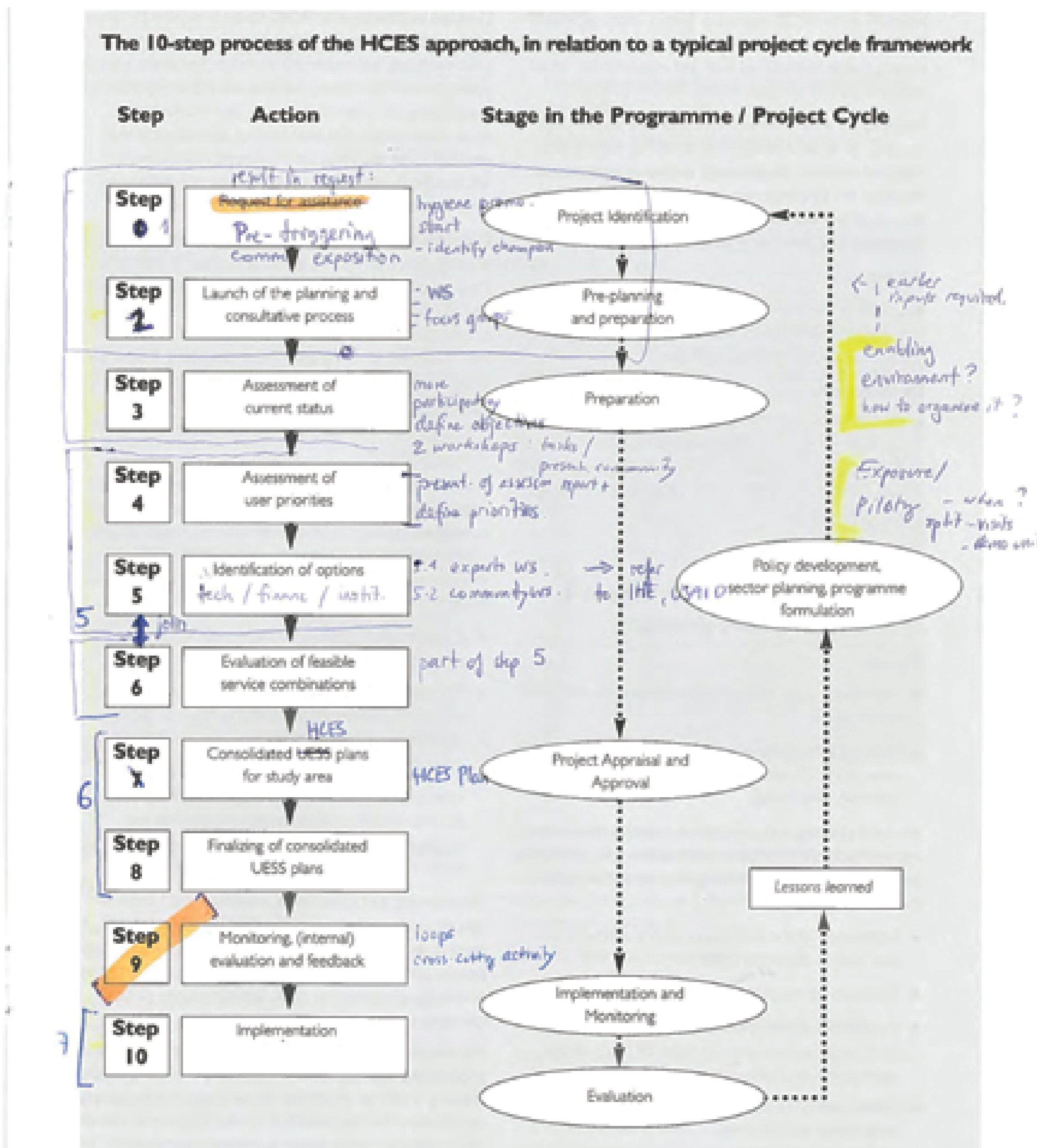
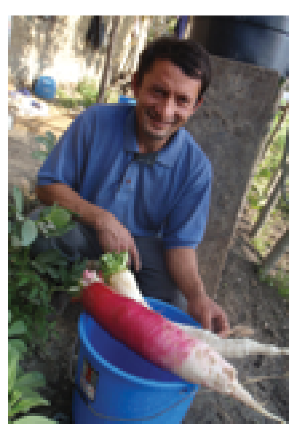
Page from Christoph Lüthi's copy of the Bellagio Principles that he took to the field for "validation in the real-world". From this came CLUES. Image courtesy Lüthi.


The 10-step process of the HCES approach, in relation to a typical project cycle framework
Step
Action
Stage in the Programme / Project Cycle
Step 1
Request for assistance
Step 2
Launch of the planning and consultative process
Step 3
Assessment of current status
Step 4
Assessment of user priorities
Step 5
Identification of options
Step 6
Evaluation of feasible service combinations
Step 7
Consolidated UESS plans for study area
Step 8
Finalizing of consolidated UESS plans
Step 9
Monitoring, (internal) evaluation and feedback
Step 10
Implementation
Project Identification
Pre-planning and preparation
Preparation
Policy development, sector planning, programme formulation
Project Appraisal and Approval
Implementation and Monitoring
Evaluation
Lessons learned

appear on just two facing pages and be visually pleasing to the reader—to make the "low-tech" technologies appeal to as many non-engineers as possible. It was designed so that anyone, including the mayor of a small town, could pick up the book and immediately understand it. The visualisation of the "Sanitation Chain" was a first. While the idea had been discussed, it had never been popularised. This helped people to question the sustainability of a project—you might be able to install 100,000 toilets, but can you close the sanitation loop? The *Compendium* was also the first time that the suite of source separation technologies were presented to potential users.

A preprint of the *Compendium* was taken to the Stockholm World Water Week in 2008. It was immediately recognised as a valuable tool and has since gone on to have widespread impact. It is one of Sandec's most visible education tools. It is available in seven languages, most recently in Arabic. In 2014, an updated second edition was published and it continues to be relevant. Like all Sandec publications and outputs, it is open source: available online and free. An interactive version, the eCompendium, is also available online. The legacy of the IRCWD persists.

Ultimately Sandec's contribution to the source separation story is an insistence to listen to the needs of the people in



← ↑
Jiban with his famous radishes and at the urine bank ready to make struvite. Photos Bastian Etter, Eawag.

far left: Poster for the STUN project in Nepali. It says: "Use urine fertiliser! Boost your soil's fertility!"

place. Source separation is only one of many possibilities that might work in low and middle income countries. Along the journey from a library and distribution center (IRCWD) to a world renowned research hub (Sandec), people working at Eawag have been able to glimpse at the huge problems in developing countries. The solutions scientists were working on, source separation among them, were important ones that have a widespread impact.

Local Example and Expertise

Jiban Maharjan is an expert on human waste as a fertiliser. He is one of many experts that you will meet if you go travelling to far off locations. He lives in Siddhipur, a small village not far from Kathmandu. He cannot read or write. He is a local farmer who knows the best ways to grow all range of fruit and vegetables. He knows exactly the best moment to fertilise cauliflower or tomatoes. When he was offered struvite fertiliser (phosphorus from urine) he was happy to try it out. By trial and error on his small farm in Nepal, he began to realise that phosphorous is but one of many nutrients you can harness from urine. If Novaquatis had proved urine as a valuable fertiliser in the lab, then taking it to the field meant engaging a whole new set of experts.

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The "pee-cycle" collected between 60-80 litres of urine per day in Nepalese villages. Photo Bastian Etter, Eawag..

Liz Tilley, with her energy, passion and commitment to making a difference to sanitation in developing countries, was a key player in bringing source separation to Nepal. Before joining Eawag, Tilley had done her Master's thesis at the University of British Columbia (UBC) on the production of struvite (a solid containing magnesium, ammonium and phosphate) from urine. At UBC, she sourced urine to conduct her experiments by collecting it from friends. Arriving at Eawag, she felt like she had found a group of like-minded colleagues. As she describes, "arriving at Eawag was like getting to Oz, where everyone understood and believed in urine—even more so than me. I felt like I had found my tribe."

Producing struvite is one of the simplest ways to make fertiliser from urine. The solid can be formed by adding magnesium to urine. It is easily filtered off, dried, and stored as a fertiliser. There are many advantages to a dried substance—it is easy to handle, it does not smell, and it can sit in a shed until the growing season.

Tilley was at a conference on water and development and met a like-minded Nepalese development worker who told her about the 100 urine diverting compost toilets that had just been installed in Kathmandu. Together they thought it a great opportunity to add value to the project by turning all that urine into a fertiliser. It was Sandec's first source separation project.

At the time Nepal did not have their own fertiliser supply so they imported it at great expense. Working in low or middle income countries is often about making small changes that add value. Former Sandec Head Chris Zurbrügg, now a member of the Eawag Directorate, explains the goal of working in many developing countries, such as Nepal:

> "The goal is to explore whether we can get more value … if there can be another incentive to do waste management … then in developing countries it will work because there are a lot of people that are unemployed but have a sense of entrepreneurship—they're looking for ways to make some money even if it is only a little bit."

The project became known as STUN (Struvite from Urine in Nepal) and was started through Eawag discretionary funding and led by Liz Tilley and Kai Udert. They were assisted on the project by Chris Zurbrügg. Together the team leveraged further funding and STUN was taken to the field. Tilley and Udert stayed in Dübendorf and hired Bastian Etter and Raju Khadka to head up the project on-site in Nepal.

Working on a technical project in a developing country offers many challenges. There is a lot of improvisation. Etter explains, "If you need a certain piece of equipment you cannot describe what it is going to be used for because they are never going to know. You always have to think, what else is it going to be used for?" As well as being technically resourceful, they also built around themselves a wide network of locals, among them Jiban Maharjan. Etter was originally sent to Nepal for four months, he stayed two years. As Etter tells, "it was a great adventure".

Building the network of partners was also about promoting the project. Kai Udert watched on when the project took on a life of its own. "One big thing, and this was particularly Bastian, was that he was good at promoting the project." In his time in Nepal, Etter learnt the language and produced a large amount of promotional material, much of it went online. Through the extensive collaboration networks of Sandec, some of that material was read by people in Ethiopia facing similar challenges to those in Nepal and they started their own struvite projects. With STUN, Eawag gained a reputation for doing interesting urine source separation work in developing countries. The opportunity to explore this further came as people in eThekwini in Durban, South Africa, learnt about the STUN project. ▪

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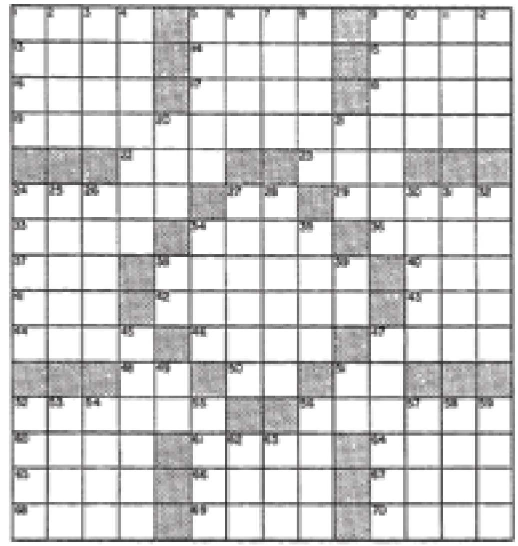
Pollution Puzzle, that appeared in the first issue of the IRCWD News, March 1971, p.11. Can you complete it?

Pollution Puzzle



Across:

1. "The . . . ", Faulkner short story
5. Biblical figure (aa = a)
9. . . . of fare
13. Early Modern English (abb.)
14. Large desert in Asia
15. Tributary of the Danube in Bavaria
16. Peruse
17. Like a bump on . . . (1,3)
18. Sea of the Antarctic Ocean
19. Type of incineration furnace
22. . . . in the hole
23. Give tit for . . .
24. Beaded one whose philosophy is in harmony with pollution control
27. European currency (abb.)
29. Desirable aim in wastes management
33. Man-eating monster
34. Wharf
36. Winter problem for public cleansing authorities
37. L'. . . de Maurice
38. Type of turbine
40. Suffix used in chemistry
41. Help!
42. Organic . . .
43. Hydrocarbon
44. Fling
46. View
47. Fewer
48. French article
50. Railroad (abb.)
51. Chemical symbol
52. Household wastes
56. Brandy
60. Old
61. Volcanic mountain in Sicily
64. Soft slime
65. Be in a state of excitement
66. Untruthful one
67. Emission
68. Faction
69. French numeral
70. Home for some

Down:

1. Landscaping feature after completion of a landfill
2. Large Australian bird
3. Chemical determination of nature (abb.)
4. Feature of bureaucracy
5. Altruistic love
6. Bakery product
7. Wind instrument
8. . . . soil
9. Scolds
10. Masculine name in USSR
11. Final
12. Luxuriant
20. Kind of reception
21. Unit of corn
24. Lift
25. Type of shelter
26. Process connected with baling
27. Remove impurities
28. "The Purloined . . . " by E.A. Poe
30. Merge
31. Afternoon treats
32. Water pitchers
34. Dinner party trouble-makers
35. Various species of deer
38. Afternoon
39. In the vicinity (abb.)
45. Sewage . . .
47. Dumping site for semi-liquid wastes
49. Adverb used in similes
51. Expression of refusal
52. Small island east of Java
53. Swiss hamlet near Innertkirchen in the Bernese Alps
54. Fief
55. Living refuse disposal units in rivers and ocean
56. Put the . . . before the horse
57. Dilemma
58. Brightly colored nitrogen compounds
59. Guaranteed (abb.)
62. Bind
63. Cat . . .

Answers appear in next issue — The Ed

The Storytellers

The scientists who told their stories for this oral history project:

Bastian Etter

Sabine Hoffmann

Tove Larsen

Judit Lienert

Christoph Lüthi

Max Maurer

Eberhard Morgenroth

Wouter Pronk

Linda Strande

Elizabeth Tilley

Bernhard Truffer

Kai Udert

Christian Zurbrügg

Chapter 4

Travel

Achievements

~ In Durban, South Africa, the nitrification and distillation process for complete nutrient recovery from urine is developed through a collaboration between Eawag, eThekwini Municipality, and the Bill and Melinda Gates Foundation.

~ Gravity Driven Membrane technology developed in Dübendorf and taken to Kenya.

Vuna Means Harvest

In late 2009, Liz Tilley was invited to a "workshop" in Durban but no one could really tell her what it was on. During her three years at Eawag, Tilley had been very busy. She was the lead author on the Compendium, she was the co-leader of the STUN project and she continued to present at conferences all over the world. Through her networks she was invited to South Africa. It was close to Christmas, she had only just been in Africa and at that time she did not feel like more travel. But she decided to go.

The workshop turned out to be a meeting between eThekwini Municipality, the University of KwaZulu-Natal (UKZN) and Sandec/Eawag. When she arrived at the workshop, she learned that Bill Gates, the billionaire philanthropist, had left only an hour before. Eawag had been selected to pursue a nutrient recovery project. Over the next week Tilley, the Bill and Melinda Gates Foundation (BMGF) project officer and researchers at the UKZN mapped out the direction of the project. It became Valorisation of Urine Nutrients in Africa – VUNA.

VUNA emerged out of Eawag's good name. In 2009, the idea of struvite recovery (inspired by STUN) travelled well beyond the borders of Nepal and the Compendium had been read by thousands in the developing world looking for an answer to sanitation issues. When BMGF decided to turn their vast resources to sanitation, it was not long before they heard about Sandec and Eawag. Indeed, the current Foundation's chief expert on transformative technologies for sanitation, Doulaye Koné, had at one time been a scientist at Sandec and even co-authored a paper on urine source separation with Wouter Pronk. The project was called VUNA, the name was chosen for its meaning in isiZulu, which is "to harvest".

Soon after the first meeting in Durban, KwaZulu-Natal, Kai Udert was brought into the project. His technical skills and knowledge in the nutrient recovery field were needed on a project of this scope. VUNA was another collaboration between Sandec and Process Engineering, with Udert as the project leader. Together Udert, Tilley and Zurbrügg developed the proposal and secured $3 million to fund the project. At the advice of the BMGF, Teddy Gounden, from the eThekwini water utility, was brought on as a co-primary investigator with Udert. Tilley knew it was a great project and decided to conduct her doctoral research as part of VUNA.

Since 1996, the South African constitution guaranteed everyone the right to sanitation. It was the role of water service providers and municipalities to implement this right. In 2003, the eThekwini Municipality in South Africa did their research on what was the best sanitation system for their peri-urban areas. Other municipalities struggled when they implemented flush toilets without the facilities to service them. EThekwini chose the urine diverting dehydration toilet because it was far better suited to the dry and hilly landscape. By 2010, when VUNA started, they had 80,000 urine diverting toilets. All of the toilets let the urine infiltrate into the ground. It was a resource that was going to waste. Eawag's background in urine separation and processing was called upon.

The VUNA project had three goals: to promote toilet use by giving urine a value, to produce a fertiliser and to reduce pollution. Two important outcomes materialised. First, was

←
Elizabeth Tilley working in the field in South Africa.

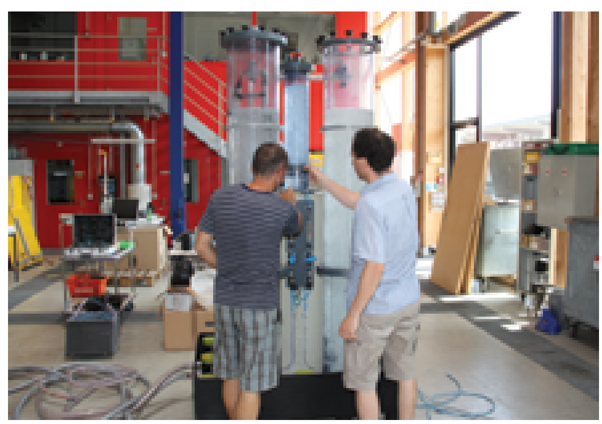
page 41: Urine diverting toilets dot the landscape in eThekwini, South Africa.

→
Urine collecting team eThekwini, South Africa. All three photos by Max Grau, Eawag.

giving urine a value. The end of this process is, of course, using source separation technologies to recover nutrients from urine which can then be processed and sold to farmers and other buyers. But to reach this endpoint requires a complex network. Urine is a heavy and smelly liquid. The great challenge was logistics. Urine must be collected from the source, taken to a transfer station, and then taken to a processing location. At each step people are paid for their part in the process. As population density of a locale decreases, so too does the economic viability of transporting urine to a processing plant. It was how to incentivise this that Tilley investigated in her eThekwini research. "Finding ways to add value to sanitation in poor countries", says Tilley, "will make the sanitation business more attractive to governments and entrepreneurs".

Tilley did two years fieldwork in eThekwini and spent another two years writing and research back in Switzerland to complete her work on VUNA. The fieldwork was challenging and rewarding. On one occasion a urine container set on fire and there was always too much work for the urine collection team to do. "I was always covered in urine" Tilley says. "But it was an experience of a lifetime and there were many good days".

Tilley's work in the region raised toilet use from 33% to 75% with minimal investment. It put cash into the families



↑
Kai Udert and Bastian Etter testing the VUNA urine reactor. Photo Andri Bryner, Eawag.

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The testing hall, Dübendorf. Photo Goran Potkonjak, Eawag.

of extremely poor people and reduced the amount of urine that was going into the ground. Most importantly, it was the first work done using the popular economic tool of "conditional cash transfers" in a sanitation context. The project identified the optimal price point at which the majority of people could be encouraged to use their previously abandoned urine diverting toilets. Urine diverting toilets, such as those used in eThekwini, are still a good choice for peri-urban locations, but the ability to collect and transport urine to a central processing place remained a challenge.

The second important outcome from VUNA was to produce a fertiliser. Initially, eThekwini wanted to do struvite recovery. But Udert was convinced there were better ways. They tried three different approaches to treat the urine: electrolysis, struvite recovery and complete nutrient recovery through nitrification. It was an interesting list. Electrolysis was tested by Max Maurer and Martin Biebow in the Novaquatis project and struvite was tested by Udert and Tilley in Nepal. Nitrification, on the other hand, had only been explored in a few projects, one of the first was Udert's doctoral research. They successfully implemented all three approaches, but it was complete nutrient recovery through nitrification that opened new pathways.

At the beginning of VUNA, nitrification and distillation was a risky technology. No one had ever tried the combination for source separated urine. Nitrification is a bacterial process that stabilises the nitrogen in urine. The two special bacteria that work to do this are ammonia-oxidising bacteria and nitrite-oxidising bacteria. For VUNA, basically a large plastic pipe (the reactor) was filled with small plastic pieces for the bacteria to attach to. The bacteria were taken from a normal wastewater treatment plant, but had to be adapted over a 60 day period to tolerate the high concentrations of nitrogen in source separated urine. The bacteria oxidise half the ammonia in urine into non-volatile nitrate. This process causes the pH to drop so that the other half is stabilised as non-volatile ammonium. From the reactor the solution is fed into a distiller. Distillation evaporates the water to yield a concentrated fertiliser solution (with water recovered as a by-product). This is simply done with using an industrial grade vacuum distiller.

The pioneering techn ology was the combination of both the reactor and distiller. It was tested at two pilot sites in Durban: the Newlands-Mashu test field-site and the customer care center of eThekwini Department of Sanitation and Water. In addition, Eawag scientists decided to make a reactor at Dübendorf. The reactor in Switzerland was to help avoid any technical difficulties so that they could communicate with their colleagues in eThekwini. Unlike in eThekwini where they needed a complex logistical network to collect the urine, there was a ready supply at Dübendorf: Forum Chriesbach.

When Forum Chriesbach was completed in 2006 it had 31 urine diverting toilets and 7 waterless urinals. For the first four years all of this valuable urine was allowed to drain into the sewer except for small volumes used for research in the lab. By 2010 when the nitrification reactor was built by the VUNA team they had a ready supply of urine to begin their pilot projects. They installed their reactor in the basement of Forum Chriesbach.

Complete nutrient recovery through nitrification took three years of research and development. With the nitrification and distillation process, Kai Udert, his team of students and post-doctoral researchers, and the project manager Bastian Etter, were able to fully achieve recovery of all nutrients in urine. This could not have come about without the VUNA project or without the close collaboration of process engineers, Sandec and key partners in eThekwini.

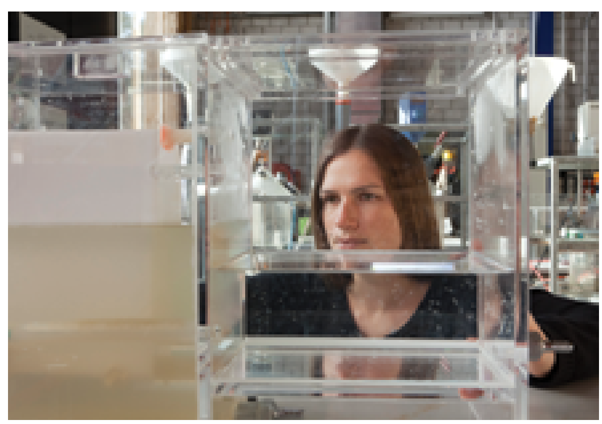
There were important alignments here between work in the developing world and technological development. As project manager on VUNA, Bastian Etter noted that during the VUNA project, "we realised this technology has potential here [in Switzerland]". The potential was large. By the end of the VUNA project, the team was granted a license by the Swiss Federal Office for Agriculture for the use of the VUNA fertilizer on flowers, lawn, and ornamental plants. And the nitrification and distillation process was in demand from many other countries, soon Etter and Udert formed a partnership with Sanergy and were advising organisations in Kenya on how to build reactors. Etter describes the sharing aspects of the technology, "one component of this is protected by a patent. But mainly it's our experience and know-how with technical details".

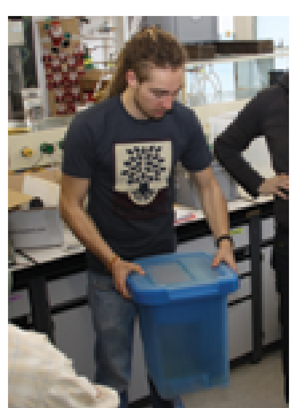
VUNA successfully concluded in 2015. The project offered a technological intervention into the existing eThekwini system of urine diverting toilets. By recovering urine there were significant environmental benefits and at the same time urine was given a value to become a resource.

It was two decades since Eawag had first pursued the idea of urine source separation in Dübendorf. But it took a project in Durban, South Africa, more than 13,000 kilometres away, to prove the concept. With VUNA the logistical problems of source separation remained, but with nitrification and distillation the technology was finally proven. A complete high quality fertiliser could be produced from urine.

Flows: Water from the Chriesbach

Much of the source separation story at Eawag is about urine separation. Considered more broadly, however, separation technologies can be applied not only to urine, but also to feces and even to contaminated water sources. All humans need water to survive. Options for cleaning contaminated water sources to potable quality are badly needed in many developing countries. While the VUNA project was





(clock wise from left) Gravity Driven Membrane Filtration, photo Andri Bryner, Eawag; Water from the Chriesbach, photo Eawag; Maryna Peter-Varbanets, photo Stefan Kubli, Eawag.

moving forward in leaps and bounds, another more humble project was completed, again process engineering and Sandec teamed-up.

Maryna Peter, another brilliant, young scientist, started out by collecting water from the Chriesbach to test the ultrafiltration process under the low pressure provided only by gravity. Early on Markus Boller initiated Marina's research. When he retired Willi Gujer supervised her dissertation on "Ultra-low pressure ultrafiltration for decentralised drinking water treatment". This became known as Gravity Driven Membrane (GDM) filtration. Wouter Pronk, who had come to Eawag to work on the Novaquatis project, co-supervised Peter on the GDM project. It was through Novaquatis that Pronk had become more convinced of decentralised approaches to water treatment. At the end of Novaquatis, he turned his attention to drinking water. Peter's exceptional work was one of the first products of this renewed thinking towards water treatment. Much of the testing for the project simply relied on water collected from the Chriesbach river that flows through Eawag's home at Dübendorf.

The GDM filtration technology is both simple and complex. It is simple in the sense that it was an idea that had stared scientists in the face for many years. Complex in the sense that so little was known about the process; there is still much to be discovered. Most approaches to cleaning water were to push it through a membrane at high pressure. At the same time a biofilm, a slimy biologically rich layer forms on the outside of the membrane. This layer is cleaned off to maintain high flow through the membrane. The unique approach of GDM filtration was to lower the pressure (it is only fed with gravity) at which the water is pushed through the membrane and to leave the biofilm intact. What they discovered was that the GDM filtration could be operated long-term without cleaning the GDM system.

When Peter and Pronk made their discoveries no one really believed them. The first paper they tried to publish was rejected many times. Colleagues thought the testing was wrong. In the biofilm field, cake theory predicted that the biofilm should clog. Of course it did, but not completely. A low but stable flow through the membrane was achieved. By visualising the structure, using Eawag's world-class facilities, Peter and Pronk were able to show why the process worked. To imagine the biofilm, you need to think of it like a sponge, it is not rigid in structure. As Pronk says "it is open like a forest on a small scale." And just like a forest, it is a biological system operating in miniature to provide an ecosystem service.

Following Peter's successful completion of her dissertation, the first place they took the technology was to Durban. Working with eThekwini, they tested the technology in the field. Following the first success of the GDM technology they then developed a portable filtration system, they called it "Safir water filter". Peter joined Sandec, working with Regula Meierhofer. They took the technology to Kenya and Bolivia and field-tested it on a large-scale.

Travelling Technologies

From 2006 to 2015 source separation travelled the world. This phase in its development was defined by a greater collaboration between Sandec and Process Engineering. Sandec provided the means for source separation technologies to travel. Whether it was expertise and contacts in Nepal or Kenya, Sandec's contribution was fundamental. At the same time, in the first decade of the twentieth century, Sandec's reputation also increased. One important publication that contributed to this was the *Compendium of Sanitation Systems and Technologies* (2008). The global water community recognised Sandec's unique contribution to the field with the IWA Development Solutions Award for Science, in recognition of the "outstanding innovation and contribution to science which has led to demonstrable uptake, impact or influence at national, regional or international levels in low and middle income countries." By travelling to Nepal, South Africa, Kenya and many other places, source separation technology was proven to be both scientifically robust and of real-world importance. In 2016, all of this came together in one technology—the Blue Diversion Toilet. ▪

Chapter 5

Together


UAE 805N

Achievements

- ~ Gravity Driven Membrane ultrafiltration is used to recycle wastewater into hand-washing water.
- ~ Blue Diversion Toilet is tested in Uganda and Kenya slums.
- ~ Eawag receives "Special Recognition for Outstanding Design of User Interface" for the Blue Diversion Toilet in the Reinvent the Toilet Challenge

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Access to sanitation is an enormous global problem. 2.3 billion people world-wide do not have access to basic sanitation. In late 2011, the Bill and Melinda Gates Foundation issued a challenge to 21 of the world's leading water research organisations. This was the "Reinvent the Toilet Challenge" and the Gates Foundation wanted nothing less than a miracle toilet. The toilet was expected to operate off-the-grid, in slums, and could only cost $0.05US per person per day to operate. It was a search for a technological innovation to solve a major global problem. Bill Gates had lived through the information technology revolution; now he wanted to initiate the sanitation technology revolution.

With its expertise in water engineering and with Sandec's reputation in developing countries, it was little wonder that Eawag was one of the research institutes chosen to take part. When the letter came through to Eawag Director Janet Hering informing her that Eawag had been selected, she had a difficult choice on her hands. She knew Eawag had the capacity to participate, but she also knew that Sandec had a reputation to uphold. As Hering says, "Sandec had a real reputation in the development community for their vision. … You can't take a reputation like that and sell it". In the end they decided to participate. But, as Hering noted, "We said we will try it our way."

The letter went out to 21 research institutes. All applied to take part and eight were selected, including Eawag. The eight participants received $400,000US and had one year "proof of concept" to present their solution at a specially organised "Reinvent the Toilet Fair" in Seattle. In a press release Bill Gates said, the selected participants, "are united by a common desire to create a better world – a world where no child dies needlessly from a lack of safe sanitation and where all people can live healthy, dignified lives."

Although the Gates Foundation was looking for technical solutions, the Eawag team knew it was about more than this. While most universities were honoured just to take part in the Challenge, Eawag scientists knew it would take technical and social solutions to solve the problem. Instead of adhering to the rules, Eawag pursued its belief in a more holistic solution.

Pieces of the Puzzle

Eawag's ability to go in its own direction and to rephrase questions to solve real-world problems is part of its fabric. In Fall 2011, with the backing of the Eawag Directorate, the Blue Diversion project commenced at Eawag. Tove Larsen, with extensive experience on running a major transdisciplinary project, was the primary investigator on the project.

Joining her in the core group was Christoph Lüthi from Sandec, who had recently developed the CLUES framework. There was also Heiko Gebauer from the Environmental Social Sciences Department and Eberhard Morgenroth and Wouter Pronk both from the Process Engineering Department. From the start the team brought in Harald Gründl from the Austrian design firm EOOS, who was an accomplished designer with experience in sanitation and sustainable design. The choice to have a designer on the team from the beginning was an important step in thinking practically about a toilet that would be used.

Source separation was at the heart of the Blue Diversion project. The Blue Diversion Toilet was set up as a urine diverting dry toilet, but with an integrated water cycle in order to allow for hand washing, anal cleansing and flushing of the front part of the toilet. An important deviation from the requirements of the call was the decision to set up a container-based toilet and not a toilet with integrated recovery of resources from urine and feces. In container-based toilets, toilet waste – in this case undiluted urine and dry feces – is transported from the toilet to an off-site treatment centre or resource recovery plant.

On-site resource recovery was restricted to the water cycle. Eawag had little expertise in physical-chemical treatment of feces and urine treatment technology for resource recovery was being developed in the VUNA project. So the new proposal concentrated on the development of the user interface (the toilet) and the on-site water cycle, which was based on the GDM filters. The project team drew upon their strong knowledge in source separation technologies and built these into the toilet.

The team also drew upon their years of experience working in developing countries. When Chris Zurbrügg and Christoph Lüthi from Sandec first started discussing the project with colleagues in other departments they were very clear that it needed to be appropriate to slums. "Chris and I said 'if you want something you can take to the field then you must think much more low-tech'", describes Lüthi. With this wide set of skills the Blue Diversion team also realised that not only could they offer technical prowess but also the potential of place-appropriate technologies.

page 49: Testing the Blue Diversion toilet in Kampala, Uganda, 2011. Photo Eawag/ EOOS.

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The first toilet project in Kampala, U-Act. Photo Christoph Lüthi, Eawag.

Designing a new toilet interface was a key part of the project. The team on Blue Diversion set out to create an "attractive" grid-free dry urine diverting toilet that provided water for both personal hygiene and hand washing. Involving Gründl from the beginning was important for this process.

Frontiers

The holistic approach adopted by Eawag was dramatically different to the other seven technically focused projects that were taking part in the Reinvent the Toilet Challenge. But Eawag still needed to respond to some parts of the project call—the team needed a unique innovation. Larsen knocked on the door of Eberhard Morgenroth and asked if GDM could be used in the toilet. She was thinking of recycling the toilet flushing water for hand washing.

Morgenroth joined Eawag's Department of Process Engineering in 2009 when he was appointed as the successor to Willi Gujer's professorship at ETH Zürich. Even before moving to Switzerland, Morgenroth's research background on biofilms and membranes was world-renowned. He was not involved in the Safir project, developed by Wouter Pronk and Maryna Peter, but he had noticed the new frontiers in membrane research opened by their discoveries. He remembers when Larsen knocked on his door and asked if GDM could work in the toilet. At the time he thought: "You're nuts. This can't work ... This idea of putting anal cleansing water into this clean water system—I wasn't sure if it was a good idea". But it was also such a unique question that it was worth investigating. He and a team of process engineers commenced working on the problem. This idea was later also developed separately from the toilet component for the recycling of hand-washing water using a Water Wall.

The central feature of the Water Wall was the GDM system (see Chapter 4). The team tried many different approaches for the Water Wall. They spent several months trying to develop pre-treatment, but the bare membrane worked just as well.

Ultimately the membrane was shown to serve as a barrier against most contaminants. After passing through the ultrafiltration system, the water was, microbiologically speaking, safe to use for hand washing.

After many trials, it turned out the GDM system was not only the simplest but also the best. Morgenroth says of the trial and error that led them to this discovery, "It is these simple issues that if you are standing in front of a whiteboard you don't see". These days, to ensure hygiene, the hand washing water is further treated with activated carbon, aeration and electrolysis to get rid of malodour and colour and for assurance against pathogens.

The membrane system was a simple and brilliant solution. Today, it has become one of Eawag's pioneering technologies that is at the frontiers of membrane research.

The Water Wall was a small success for the larger project. But it was also a tribute to the capacity for Eawag to find solutions. As Wouter Pronk, who also worked on the Water Wall, reflected, "It's also part of the culture at Eawag, that we are not making little houses where you protect your own research. But that it is very open communication between the groups and the projects. I never experienced that there were these big walls, which you have at universities." Surprisingly, GDM just worked. People like Wouter Pronk were able to make their contribution and move on to other projects. But Blue Diversion was about much more than just the Water Wall, it was a toilet that would be used.

The Test

The unique nature of Eawag is its ability to bring the many disciplines operating within its walls into conversation. The social scientist Sabine Hoffmann describes it well, "What is special at Eawag is that you have these experts who are interested in working together. And they believe in something new. They share this common interest in developing something together." Putting Blue Diversion together was about having a multi-disciplinary team and taking it to the field.

In the Reinvent the Toilet Challenge, the Eawag team did it their way, as the Directorate had encouraged. With an innovative technology at hand, in the form of the Water Wall, the team set about finding the best possible interface.

Unlike all other teams that entered the competition, Eawag offered a field test within the first year. This was an ambitious task. Today, nearly a decade on from the first challenge some entrants into the competition are only just going to the field to test their technologies. But the team knew that they must go to the field and ask users what they wanted.

Christoph Lüthi knew the perfect place to test their ideas. A few years earlier while attending the WaterAid conference in Nairobi, Kenya, an enthusiastic young Ugandan student introduced himself to Lüthi. This was Innocent Kamara Tumwebaze and he had just completed his master's dissertation on dry toilets in Kampala, Uganda. Tumwebaze suggested that Lüthi contact his professor, Charles Niwagaba, at the University of Makerere in Kampala. Energetic and keen to make changes, Niwagaba became a crucial on-the-ground collaborator with Sandec on many projects in Kampala. One of the first projects they worked on was the Urban Affordable and Clean Toilets (U-Act) project. In 2011, with the help of Niwagaba and Tumwebaze, the Eawag team took its first prototype toilet to the Kampala slums.

Taking the toilet to the Kampala slums was a necessary step in developing their interface. It was something new for many in the project team. Tove Larsen had never been to an African slum. Lüthi told her, "Tove, if you want

The first field test in Kampala. Photos Eawag/EOOS.

to reinvent the toilet you have to come. You have to see this." This was an important turning point for Larsen, who was able to witness the great challenge of providing sanitation to world's poor. She also knew this was an important moment for her as a researcher, "For me it was important to get a sense of the people who would use the toilet". Along with Lüthi and Larsen were two designers from EOOS, who also made their first visit to a slum.

The field-test in Kampala intended to find what people wanted in the toilet. The team brought only a very rough design prototype. It was a mock-up model, made of Styrofoam, fitted with a camping style toilet in the bottom and hooked-up to a water pump to replicate the Water Wall. They did a preference workshop with residents of the slums where people could rank what they liked, what needed to change and how it would be used. They surveyed the locations where the toilet would be installed. And they listened to people. They spent five days working out the design. For people, hand-washing and having a nice design were very important. From Kampala, the team members gathered a large amount of data that they could build into their final design.

The Kampala field test also had an impact on morale within Eawag. Christoph Lüthi explains that the Kampala fieldwork, "brought cooperation within Eawag to a new level. I think they had more respect for what we [Sandec] do." He goes on, "I think the [Blue Diversion] project was important for that, all interdisciplinary projects for that matter." When disciplines work well together on a project cohesion within the institution increases and along the way the capacity of the institution to successfully complete challenging transdisciplinary projects also increases.

If people in Sandec felt more respected after showing their skills in Kampala, then others outside of Sandec also noticed their important contribution. Eberhard Morgenroth described the work of Sandec, "They might not be aware of it, but Sandec brings very essential expertise to the table." He went on, "I am actually worried. If I look at some universities who develop technologies for developing countries, they are missing a key part. They don't have a Sandec."

Seattle, 2012

With the Water Wall showing promising results and the first field test completed, the designers at EOOS set about finalising the toilet. In Spring 2012, the toilet was fabricated and produced. By August, the first model of the Blue Diversion toilet was ready.

On 14-15 August 2012, the Bill and Melinda Gates Foundation hosted the "Reinvent the Toilet Fair". As the Gates Foundation described, it "showcases innovations from around the world that are creating a new vision for the next generation of sanitation". As well as the eight institutions that were showcasing their new toilets, there were 26 other institutes and companies showcasing products that were aligned with the reinvent the toilet challenge. It brought together experts from 29 countries to discuss the future of sanitation technologies.

Eawag did not win the challenge. First prize went to the California Institute of Technology for a solar powered toilet that produced hydrogen and electricity. Second prize went to Loughborough University, UK, for a toilet that produced bio-char, minerals and clean water. Third prize went to the University of Toronto for a toilet that sanitised urine and feces and recovered clean water. Remember that Eawag did not follow the rules – it was primarily the lack of an option for feces treatment that ruled them out, in addition to the insistence on having urine and feces collected and treated off site. Based on the Eawag experience, it was clear to the team that it was not possible to provide a proof-of-concept for on-site treatment of feces and urine within 12 months (this is now the topic of Blue Diversion Autarky). They also knew, through Sandec, that a high-tech toilet would not really work in a slum.

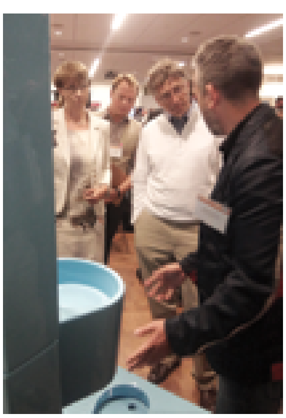
Eawag offered a model that was most fitting to the slum environment. They were the only ones in Seattle with a functioning toilet and they were the only ones to have field tested their ideas. Blue Diversion's aspirational design, built from knowledge from the field and from Harald Gründl's skill as a designer, impressed everyone in Seattle. In recognition of their efforts, Eawag and EOOS were awarded, "Special Recognition for Outstanding Design of a User Interface", and with it came a $40,000 prize. By combining the skills of engineers, social scientists and development experts, Eawag's Blue Diversion toilet was visionary.

Blue Flows

Eawag received huge publicity with the success of the project. "Blue Diversion has given Eawag huge traction," says Christoph Lüthi. Following the success, Eawag received follow-up funding from the Gates Foundation for other projects. Further field testing and social studies in Kampala and in a much more challenging slum—Mukuru, Nairobi—were funded. The Water Wall also received further funding. There were more flows from the project than just funding. There was capacity and collaboration. As discussed above, institutional cooperation reached new levels through the Blue Diversion project, which continues as an important Eawag project. After Seattle, it proceeded through phase two (2012-2014) of research and development. In 2014, it went on to win the first prize in the region Europe/West Asia and the runner-up prize globally in the project innovation awards for Applied Research from the IWA. The team is seeking industrial partners to move the initial design into production.

In 2015, Blue Diversion Autarky was born. This new phase of the project is led by Kai Udert and fully embraces the Gates Foundation's high-tech vision while still being based on the source separation concept. The ambition of the new project is to operate completely off the grid with a range of innovative technologies. This includes a collaboration with the Paul Scherrer Institute, another member of the ETH Domain, to treat feces with supercritical water oxidation.

There were also other successes for Eawag that were far less visible. The research team gained confidence from Blue Diversion. If we cast our mind back to the challenges of Novaquatis (2001-2006, Chapter 2), Blue Diversion shows that Eawag learnt how to overcome the onerous challenges of transdisciplinary research. It was still a difficult project. Eberhard Morgenroth described the challenges of working on the large transdisciplinary project.



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Bill Gates looks at the Blue Diversion Toilet, Seattle, 2012.

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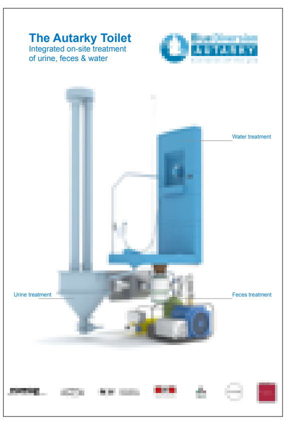
The Eawag Team with the Blue Diversion Toilet in Seattle, August 2012. Photo Christoph Lüthi, Eawag.

> "It was a nightmare. If it was up to me I would have said we need two generations of doctoral students to develop the technology followed by a generation of designers. But luckily there was Tove. She is excellent in understanding the potential of people, the personal hopes and fears of people, and also the greater direction. It was essential for the Blue Diversion project to develop in an interdisciplinary team and not sequentially."

A fundamental part of Larsen's ability to manage Blue Diversion was her experience on Novaquatis. As Larsen said, "Blue Diversion was much easier to work on than Novaquatis because it had this clear goal of producing the Blue Diversion toilet and we also had more experience of course." Within one year Blue Diversion achieved a great deal – they produced a field test and an aspirational design for a new toilet.

Blue Diversion was as much a pioneering technology as a symbol of Eawag's institutional ability to successfully complete major transdisciplinary projects. As Janet Hering describes, "it symbolises interesting cooperation between engineers and Sandec and also a way in which there is a cross-fertilisation between opportunities to develop technologies in industrialised countries like Switzerland and in a developing country context."

Blue Diversion was not just a serendipitous success. Eawag's ability to manage the project dates back to 1992 with their early ambitions to develop urine source separation; it dates back to 1995 when Sandec was established; it dates back to 2000 with Novaquatis; it dates back to 2006 when the Directorate believed that source separation was important and installed urine diverting toilets in Forum Chriesbach even though technologies were not quite ready. The capacity of Eawag in the field of source separation was two decades in the making. It took many years to bring Blue Diversion together. ▪



Clockwise from top left: Blue Diversion Autarky, the next generation; testing the Blue Diversion toilet in the Mukuru slum, in Nairobi, Kenya, 2014; fine tuning the Blue Diversion toilet in the testing hall Dübendorf; in the Mukuru slum. Photos Eawag, upper right Andri Bryner, Eawag.

Infographic. Travelling Technologies.

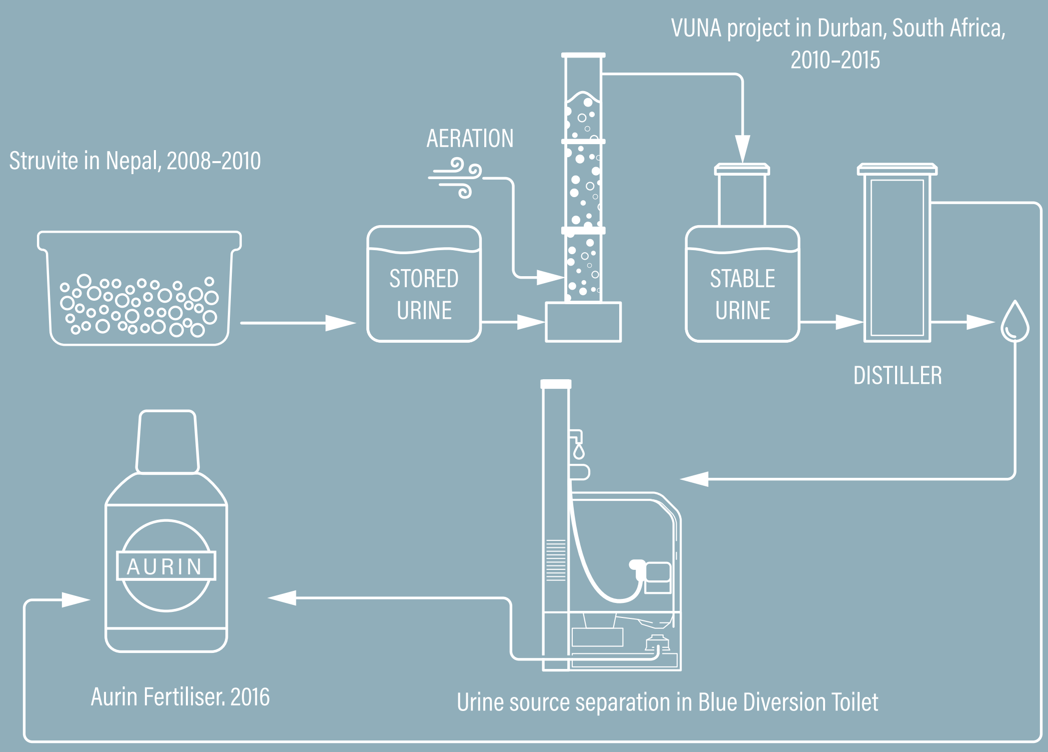
#1 Gravity Driven Membrane Filtration (GDM)

Water taken from the Chriesbach.

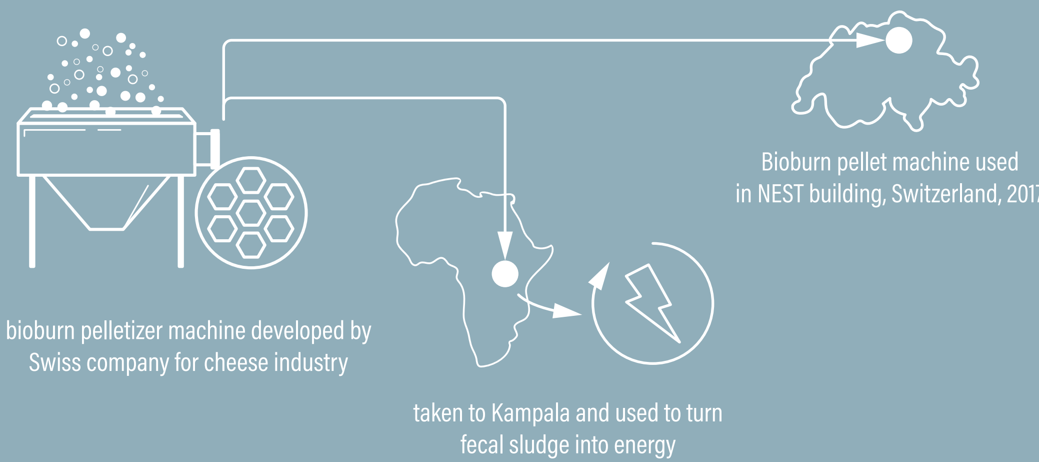
GDM is taken to Kenya for the Safir Project.

GDM filtration forms the Water Wall for the Blue Diversion Toilet

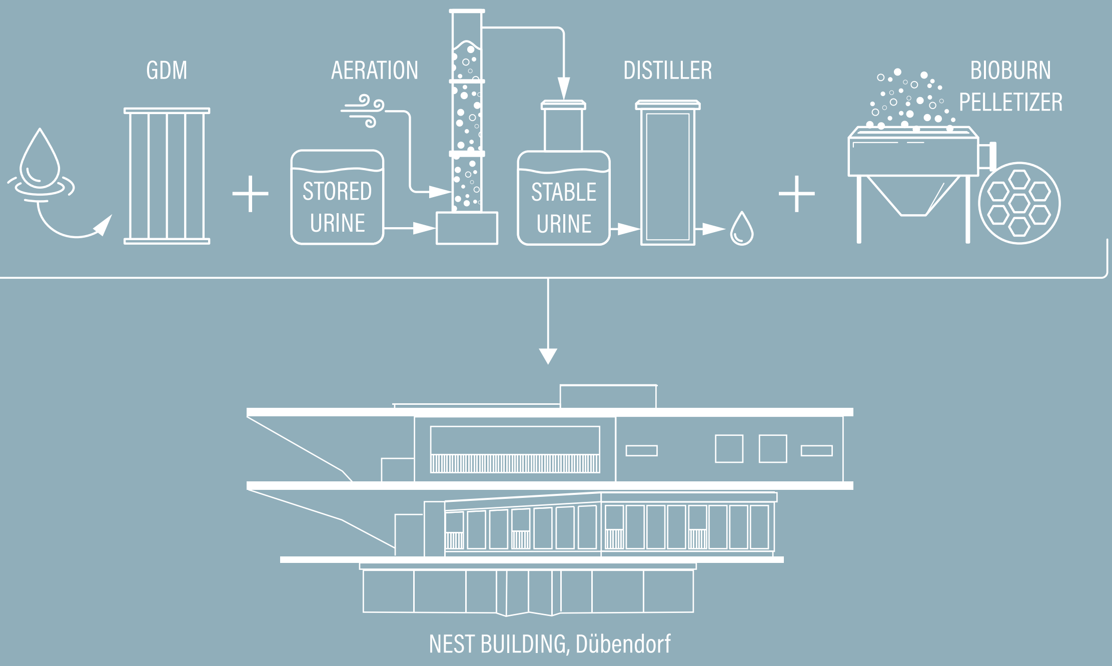
#2 Urine Nitrification and Distillation



#3 Bioburn Pelletizer



#4 It all flows to the NEST



Chapter 6

Home

Achievements

- ~ Vuna Ltd. is created and one of its first jobs is to turn urine from Olma into a valuable and marketable fertiliser.
- ~ Water Hub in the NEST building opens in Dübendorf with important source separation technologies built into it.

Olma's Harvest

Dölf Sutter is an energetic 70-year-old Swiss carpenter. In October each year, Olma agricultural and nutrition fair in St. Gallen hosts hundreds of thousands of people for Switzerland's largest fair of its kind. In 2015, Sutter a leading figure in the town, had a problem. Everyone was taking their toilet breaks all over St. Gallen. Over the ten days of the festival people bet on pig races, watched processions by the guest canton, and ate and drank and enjoyed the quality of Swiss produce. In between all this fun people also needed to take natural breaks. In 2015, Sutter thought he had solved some of the problem by placing a portable toilet near a particularly over-used site near a local restaurant. But the waste, particularly the urine, had to be emptied by vacuum trucks and transported to the sewage treatment plant because there was no connection to the sewer.

Late in 2015, Eawag got a call from Sutter. "We need your process," he said. Sutter had read about the ground-breaking work Eawag was doing on urine source separation, in particular the Vuna process, and believed that the technology could have a real benefit for Swiss agriculturalists. The urine from Olma's portable toilets was collected throughout the 2015 festival and then transported to Eawag. The Vuna nitrification and distillation reactors were used to process the Olma urine and soon enough it was turned from waste to resource.

On 1 April 2016 it was no joke when Sutter held a press conference in St. Gallen and showcased the fertiliser that had been created from Olma's urine. One way to clean up St. Gallen and make people more conscious of their waste was to change their thinking—urine was a resource. Sutter told the Swiss press that the way they created this fertiliser was with Eawag's science. Bastian Etter oversaw the processing of the Olma urine, he remembers that "it was a wide success".

Eawag again was shot into the spotlight, not for their innovative technologies or their work in developing countries, but for bringing their science to the help of Switzerland's most loved agricultural show. Urine source separation, after a long global journey, had arrived home.

For Olma 2016, Eawag was invited back to showcase their newest commercial venture: Vuna Ltd. After the success the previous year, they were given pride of place at the central square at the heart of Olma. More than 365,000 people attended Olma in 2016 and most of them saw the work of the Vuna company. At Olma, Eawag had its nitrification reactor and distillers and processed urine from the Olma urinals into a fertiliser. Also on sale was Vuna's commercial fertiliser named "Aurin". Again in 2016, urine from the Olma urinals was recycled using the Vuna process to become a fertiliser. Volunteers from Eawag staffed the Vuna tent. The volunteers included many former staff and students who had worked on urine source separation over the years; they were proud to showcase their technology to the Swiss public.

In 2015, after the VUNA project finished in Durban, Kai Udert and Bastian Etter realised that they had an interesting product on their hands. Using the nitrification and distillation process they could create a complete and valuable fertiliser. They had it certified by the Swiss Federal Office for Agriculture and created the Vuna company. Their marketable product was Aurin fertiliser.

It took one year to build the business to a place where it was ready to launch. Soon after the Olma success, Vuna Ltd., a spin-off company of Eawag, was founded.

After Durban, Bastian Etter went on to become the managing director of Vuna Ltd. He has been working on source separation for nearly a decade, seeing the birth of Vuna Ltd. was a highlight for him: "When I first started working on these projects people laughed at me". Etter goes on, "to realise the change in people's minds that now it suddenly becomes acceptable. When I show up with my fertiliser bottle and people say "Wow. This actually does work.""

Kai Udert has worked on source separation for two decades but his sentiments reflect Etter's: "I think the major highlight is that we can produce fertiliser from urine and that we can market it and we can sell it." Udert goes on to reflect on the history of urine source separation, "That was our initial idea that we recover resources and that we make value out of urine. And we did it." Vuna Ltd. is the culmination of a long Eawag journey working on urine source separation.

Recently, a resounding success of Vuna Ltd. was that Aurin was granted an unlimited license to be used on all crops including edible plants by the Swiss Federal Office

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Aurin Fertiliser. It now has an unlimited license to use on all crops, including edible plants. Photos Bastian Etter, Eawag.

↓
Vuna Ltd. at Olma, 2016. Photos Bastian Etter, Eawag.

page 61: St. Gallen, Switzerland, 2016. Photo Shutterstock.

for Agriculture. It is the world's first urine-derived fertiliser to obtain such an approval.

Nesting

The source separation journey began with testing urine but along the way Eawag has gained the capacity to deal with various products of source separation, including greywater and feces. Nowhere is this more visible than in the new NEST building. NEST stands for Next Evolution in Sustainable Building Technologies. The concept was first proposed by Eawag and Empa in 2009 in the context of providing housing for visitors. Like Eawag, Empa is a research institute in the ETH Domain but with a focus on materials science and technology and about twice the size of Eawag. The two research institutes are co-located on the Dübendorf site. The concept evolved during the many years that it took to secure the substantial funding needed to bring NEST to fruition. In May 2016, NEST was opened at Dübendorf, a short walk from Forum Chriesbach.

NEST is a cutting edge building in which new technologies for living and working spaces of the future are developed. It consists of modular parts where different building techniques are tried, tested and validated in real-life conditions. For the construction, energy and water industries getting a new product onto the market is often a long and slow process. NEST hopes to get well-engineered products out faster. It is a collaboration between research, industry and the public. There is a next generation three-bedroom apartment where people live; there is also a fitness studio where people work-out and enjoy a spa. People live, work and play at NEST. It is here that the newest sustainable technologies are tested so that with their uptake we can limit our impact on the environment.

To be sure, NEST is an Empa building. But Eawag played an important role in taking NEST from a good idea to an actual research building. Eawag Director Janet Hering worked closely with the ad interim Empa Director Peter Hofer and his successor Gian-Luca Bona to see the building

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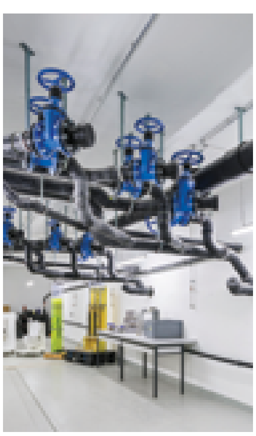
Testing the Self, an earlier Empa and Eawag collaboration, 2010. The self uses gravity driven membrane for its water treatment. Photo Beat Geyer, Empa.

concept move into production. NEST demonstrates the very good working relationship between Empa and Eawag.

All buildings need access to water. In NEST, water is managed in the Water Hub, the newest location for developing Eawag's source separation and treatment technologies. It is a way to test real-life conditions for Eawag's source separation technologies. Working on the NEST project are Bastian Etter, Tove Larsen, Eberhard Morgenroth, Linda Strande and Kai Udert. When Larsen represented Eawag on the board that oversaw the development of NEST, she was insistent that the building must have capacity for source separation technologies. As a consequence, the NEST infrastructure does not have the standard single wastewater pipe but five. They were expensive pipes to put into the building, but the cost was necessary to take source separation to the next step in application to real-life conditions.

Each of the five pipes in NEST is for a different component in the source separation process: urine, light graywater (from showers, washing machines and bathroom sinks), heavy graywater (from kitchen sinks), black water (fecal matter) and the last pipe, just in case, connects mixed wastewater to the sewer. Ironically, when the plumbers were connecting the pipes in NEST, they were unsure what all the pipes meant so they just connected the entire system to the one sewer pipe. The problem was later resolved but it did remind the team to stay in constant contact with all stakeholders to explain how to work with new source separation technologies.

The five pipes at NEST lead to familiar technologies. The urine pipe leads to a storage tank and is treated using the Vuna process. The fertiliser produced is sold to the visitors of the building. The greywater is treated using a membrane based process, as adapted for the Blue Diversion Water Wall. The treated water will recirculate within the building for tests on microbial safety conducted by Frederik Hammes and Tim Julian. The eventual hope is that the treated water could be used not only for toilet flushing but even for washing machines and ultimately maybe for showering.



↑ The Water Hub at NEST. Photo courtesy Empa.

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The NEST building. Photo Courtesy Empa.

The membrane technology that they are now adapting to greywater is the next step in research pioneered in Blue Diversion project. Morgenroth believes that within the next decade the membrane based technologies they are developing will become widely used.

The black water pipe leads to the most recent and exciting source separation process. Linda Strande, who leads the Management of Excreta, Wastewater and Sludge Group in Sandec is using the NEST building to pioneer new ways to process fecal sludge. Feces are largely made up of organic matter (carbon), a resource that can be used as a fuel. When feces come out of the black water pipe they are dewatered, treated and then turned into pellets which can then be burnt to generate power. The process was pioneered by Strande in Kampala, where she worked with Charles Niwagaba on the SEEK—Sludge to Energy Enterprises in Kampala—project.

Strande joined Eawag in 2010, arriving from the University of KwaZulu-Natal, Durban where she worked after completing her Ph.D. at the University of Washington (US). Now she is a tenured researcher with an exciting future. Strande worked on the early phases of the VUNA project and described Eawag by saying: "In general it is a really great place to work. I always say it is like summer camp for the really smart kids."

Strande's expertise is in fecal sludge management. Fecal sludge usually contains urine, but urine source separation allows for the fecal sludge to be transported in a black water pipe to the basement of NEST.

One of Strande's talents has been to look at available technologies in Switzerland and reinvent them for use as resource recovering sanitation technologies in both developed and developing countries. One example is the Bioburn pellet machine that she will be using in the NEST building. The Bioburn pellet machine was developed by a Swiss company for the cheese industry to reuse waste. In short, it turns unused biomass into dried pellets for resource recovery. When Strande first saw the machine in 2014, she knew it would be perfect for fecal sludge. She has since tried it in Kampala and is developing the technology further in NEST. This is another unique example of a technology travelling from Switzerland to the developing world and returning home with significant impact.

The Water Hub at NEST is yet another collaborative project across Eawag. If we look at the four source separating pipes, there is Strande looking after the blackwater pipe, Udert and Etter looking after the urine pipe and Morgenroth and Larsen looking after the greywater pipes. Working together in the same building, the members of the Water Hub team are testing new source separation technologies for application in Switzerland and around the world.

If you tour NEST, you might be lucky enough to have Bastian Etter to show you around. He will tell you something important about what you are witnessing in NEST. In a few decades, much of what is built in here will be common practice. Etter says about our current system of urban water management:

> "I see we are at the beginning of a big change ... The current system, if we look at it, you can see from much of the research that is going on now, it is the agony of the dying system, we are trying to optimise the energy consumption of wastewater treatment plants, just like people are trying to optimise the fuel consumption of the combustion engine. The system will change. I don't know how it will change. But source separation will become more important ... Over time maybe faster than we think things will change."

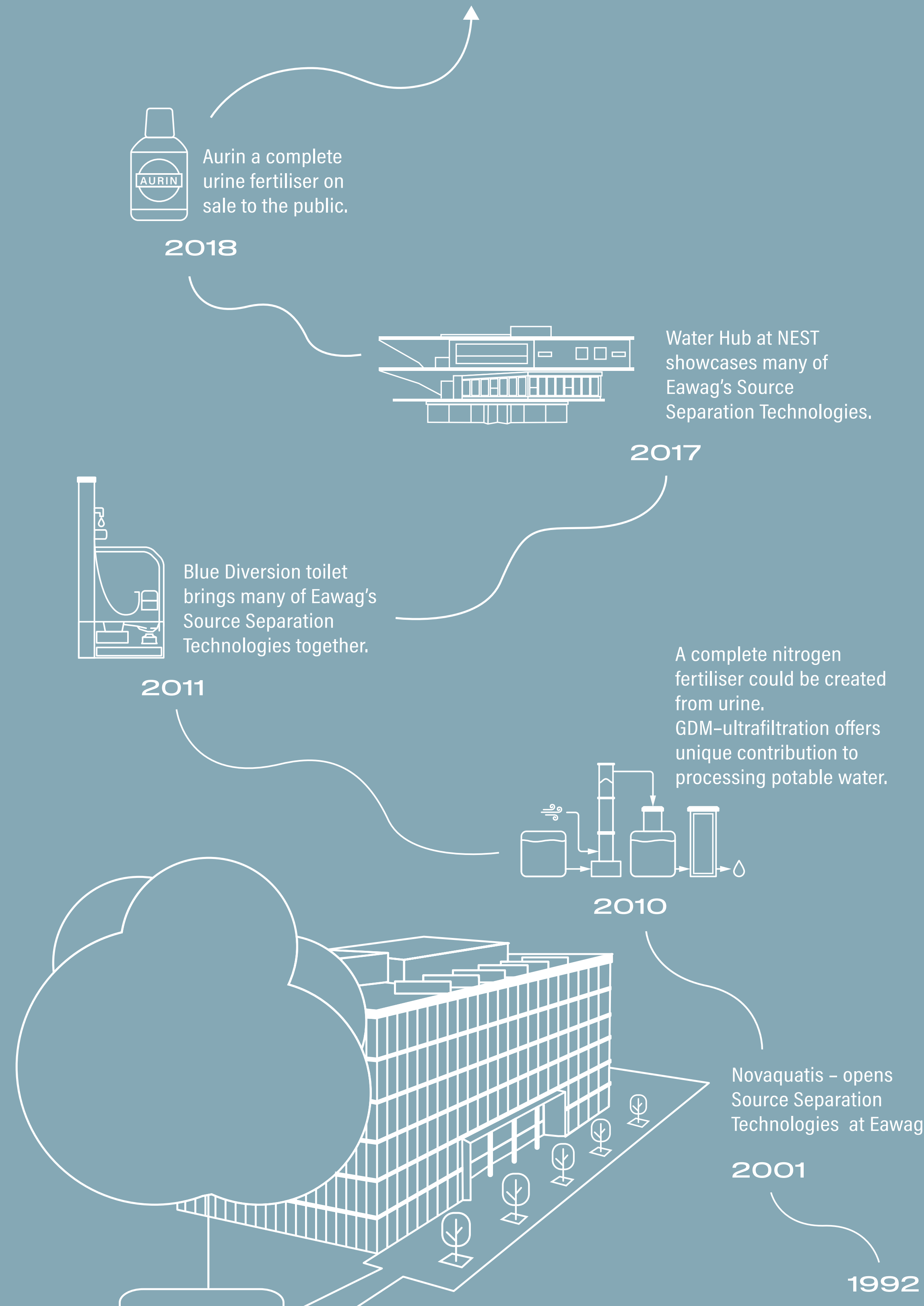
→
The Chriesbach flowing, Dübendorf. Photo Andri Bryner, Eawag

Arriving Home

NEST allows Eawag to develop source-separation technologies for future applications and to prepare people for the next urban water challenges. But we can also see that getting prepared for the future takes time. Olma is the shining example showing that, after their long global journey, source separation technologies arrived back home to bring great benefits to the Swiss public. Vuna was a product that many people in St. Gallen and members of the agricultural sector were proud of. So too the five pipes installed at the NEST building can be seen as symbolic of a bigger journey. They are the culmination of a quarter of a century of questioning the accepted knowledge on urban water management.

In the previous chapter we saw how Blue Diversion brought together Eawag's source separation technologies to solve important problems in middle or low income countries, but NEST brings this work home. It shows how Eawag's research technologies also make significant contributions to resolving urban water issues in Switzerland. ▪

Flowing with each project along the way the capacity of the institution to tackle challenging transdisciplinary projects grows. Eawag built their capacity in the field of source separation technology.


AURIN
Aurin a complete urine fertiliser on sale to the public.
2018
Water Hub at NEST showcases many of Eawag's Source Separation Technologies.
2017
Blue Diversion toilet brings many of Eawag's Source Separation Technologies together.
2011
A complete nitrogen fertiliser could be created from urine.
GDM-ultrafiltration offers unique contribution to processing potable water.
2010
Novaquatis – opens Source Separation Technologies at Eawag.
2001
1992

Conclusion

Scientific achievement may take a career, often it takes longer. The questions that drive momentum are always evolving and leading to new discoveries. This insistent drive to solve multi-disciplinary problems is a fundamental part of how Eawag operates. Scientists do this together through a collaborative effort. Unlocking source separation technology for the urban water sector is one example. For twenty-five years Eawag has pioneered fundamental change in how scientists understand urban water management in both developed and developing countries.

Flows of Science has charted the dynamic story of source separation technology at Eawag. By looking at the history of source separation at Eawag we can see that it took time to develop the capacity to deal with these real-world problems. At each turn, with every project, Eawag was able to flow into the next success. The story reveals the value of institutional capacity—an intangible asset that developed over decades.

Developing source separation at Eawag shows that when disciplines worked well together on a project, cohesion within the entire institution increased. Along the way the capacity of the institution to successfully complete the next challenging transdiscipilinary project also increased. This is most evident with the Novaquatis project. While successful in opening the scientific field of source separation, it had a much larger impact in flowing into the next projects. The large amount that the Blue Diversion project achieved in its first year (2011-2012) was in many ways due to very good project management, which stemmed from the Novaquatis experience.

Tove Larsen has played a pivotal role in paving the way for source separation at Eawag. She pursued the ideas in the early 1990s even though they pushed against all conventional thinking on urban wastewater management and she encouraged others at Eawag to get behind source separation. Larsen led Novaquatis and went on to successfully lead Blue Diversion. So too did Kai Udert make important contributions to many source separation projects, Vuna Ltd. is his most recent and exciting venture. These are but two of many engineers who have spent their careers pursuing source separation.

Capacity, as this story shows, is always about collaboration. Working at Eawag is about working together. This is as much about how the Directorate operates as it is about how research projects operate. If the Director cannot attend an important event, then another member of the Directorate will smoothly step-in. On the project level this collaborative effort is visible in the Wings project, Eawag's next major strategic project. It includes many senior researchers, including professors, but is managed by a newly-tenured researcher, Sabine Hoffmann. Collaboration at its best is when members of different disciplines work together. At

Eawag they do this because they know they will make a real-world difference. This is evident in so many source separation projects, such as VUNA, Gravity Driven Membrane Filtration, Blue Diversion and NEST.

One of the most compelling streams of this story is the journey that source separation technologies needed to take in order to achieve prominence. Would Novaquatis have had a long-lasting impact if its young researchers inspired by the project did not take source separation to the developing world? Would a complete fertiliser from urine have been produced without the VUNA project in South Africa? Would gravity driven membrane filtration have had such success were it not for Blue Diversion toilet and testing the Water Wall in Kampala? The journeys that the technologies took were nothing short of incredible.

The transfer of knowledge between the global North and South will continue in the future. Countries like China and India and South Africa do not have technological lock-in and offer interesting opportunities for the uptake of new and innovative technologies. We see this in the source separation story, where Sandec added significant capacity to many projects. Developing countries were important sites for creating and testing technologies. That Eawag, as an institution, can cover the breadth of the globe through its research also allows for many fruitful projects to develop and have a lasting impact. Some of Linda Strande's new innovations with technologies, such as the BioBurn pellets, are evidence of this continuing into the future.

Flows of Science was built out of a very intimate approach. The craft of history is to describe human endeavor, with all its nuances, through stories. These were drawn from oral histories told by scientists who played important roles in bringing source separation to prominence at Eawag. Scientists, we must not forget, are also people and storytellers. For all the porosity of such an approach there is a deep truth. Science, good science, takes time and teamwork. Innovation is not a moment, it is a process. To deliver source separation technology as an innovative new approach to urban water management took teams of people working together over decades. ▪

ANS	Anthropogenic Nutrient Solution
BMGF	Bill and Melinda Gates Foundation
CLUES	Community-Led Urban Environmental Sanitation Planning
EPP	Eawag Partnership Program
ETH Zürich	Swiss Federal Institute of Technology in Zürich (Eidgenössische Technische Hochschule Zürich)
ETH Domain	Domain of the Swiss Federal Institutes of Technology, comprising ETH Zürich and ETH Lausanne as well as the four research institutes Eawag, Empa, PSI and WSL
GDM	Gravity Driven Membrane Filtration
HCES	Household Centred Environmental Sanitation Approach
IHE Delft	IHE Delft Institute for Water Education, formerly UNESCO-IHE (Institute for Hydraulic Engineering)
IRCWD	International Reference Centre for Waste Disposal
IWA	International Water Association
Novaquatis	A transdisciplinary project on urine source separation
NEST	Next Evolution in Sustainable Building Technologies
NGO	Non-governmental organisation
Olma	Swiss agricultural and nutrition fair held annually in St. Gallen
Safir	A household filter to produce drinking water using GDM technology
Sandec	Sanitation, Water and Solid Waste for Development, a research department at Eawag
SEEK	Sludge to Energy Enterprises in Kampala
STUN	Struvite from Urine in Nepal
SuSanA	Sustainable Sanitation Alliance
U-Act	Urban Affordable and Clean Toilets
UBC	University of British Columbia
UKZN	University of KwaZulu-Natal (ZA)
VUNA	Valorisation of Urine Nutrients in Africa, a project funded by BMGF that led to the formation of the spin-off company Vuna Ltd.
WHO	World Health Organization
Wings	Water and sanitation innovations for non-grid solutions, an Eawag strategic program

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Unless otherwise noted, all images in this report were sourced from the Eawag communications library and are copyright of Eawag. All illustrations by Cass Urquhart.

This report was compiled from oral history interviews conducted with Eawag scientists. These were conducted in September and October 2017. The bulk of the interviews were conducted at Eawag, Dübendorf, 8 to 21 October 2017. There were 14 interviews. Interviewees were Bastian Etter, Janet Hering, Sabine Hoffmann, Tove Larsen, Judit Lienert, Christoph Lüthi, Max Maurer, Eberhard Morgenroth, Wouter Pronk, Linda Strande, Elizabeth Tilley, Bernhard Truffer, Kai Udert, Christian Zurbrügg. There were also two focus groups, one at the NEST building and another with early career researchers. In total 20 scientists were directly involved with the project, each interview and focus group ranged in length from one to three hours. In total 30 hours of interviewing was conducted.

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About the Author

Dr Luke Keogh is a historian and curator. His research and writing has received many awards, including the Redmond Barry Fellowship from the University of Melbourne and the State Library of Victoria (2017-18), the Sargent Award from the Arnold Arboretum of Harvard University (2015-16) and the Gerda Henkel Research Scholarship (2014-2017). He has also worked at many museums around the world.

He was one of the lead curators on the internationally acclaimed exhibition Welcome to the Anthropocene: the Earth in our Hands (Deutsches Museum, Munich, 2015-17), which included the Blue Diversion Toilet as one of the many objects on display.

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