DISCUSSION PAPER

Capital Regional District
Core Area Wastewater Management Program

Integrated Resource Management Strategy

Discussion Paper – Urine Separation
031-DP-8

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1 Objective

This Discussion Paper provides an overview of the concept of urine separation from wastewater. The subject is one of considerable complexity, since it extends beyond recovering a potential resource from wastewater. Urine separation also offers the potential to significantly reduce energy use in wastewater treatment, while at the same time improving effluent quality in the context of micro-constituents. Besides speaking to these sub-topics, the paper identifies the current state of concept and technology development and application. The paper also examines the regional reuse potential for urine reclaimed from wastewater generated within the Capital Regional District in the context of the Core Area Wastewater Management Program.

2 Topic Area Overview

2.1 Urine Separation Drivers

Urine separation refers simply to the separation of urine from the main wastewater stream, either wholly or in part, at its point of generation. Eawag (Swiss Federal Institute for Aquatic Science and Technology), which is a Swiss-based and internationally linked water research institute, has coined the phrase "NoMix" for a wastewater management strategy centered around urine separation (Larsen and Lienert 2007). They also offer a succinct description of the central technology:

> *The "NoMix technology" concept is also simple: urine is collected in the front compartment of specially designed toilets and drained, with a little flushing water or even undiluted, into a local storage tank. The back compartment of these toilets operates on the same principle as conventional models; the waste material collected is flushed into the sewers.*

The description above immediately leads to several questions. But before discussing concepts and technologies associated with urine separation, in the context of these detailed questions, it is worthwhile to examine first a basic question – why consider urine separation as an element in wastewater management? This question can be answered by examining three main drivers:

- alternative fertilizer source
- wastewater treatment impacts
- micro-constituent control

Alternative Fertilizer Source

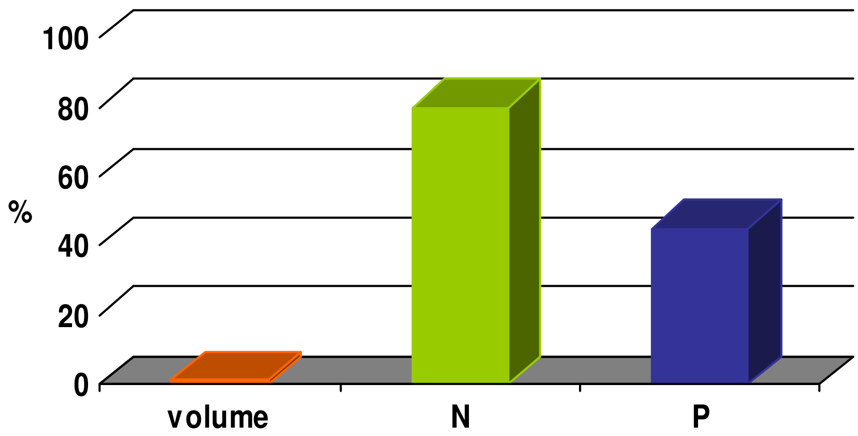
Liquid Ammonia Fertilizer Application

Nitrogen, in the form of urea, potassium and phosphorus are the dominant chemical constituents of urine (Kujawa-Roeleveld and Zeeman et al. 2006). These same constituents are also the primary crop and plant nutrients and, as a result, urine is a potential fertilizer. What is attractive of using urine as a fertilizer is the displacement of commercially manufactured fertilizer use: nitrogen-based fertilizers are created through the Haber-Bosch process, which applies energy to combine natural gas (methane – CH_4) and atmospheric nitrogen (dinitrogen – N_2) to form ammonia; phosphate-based fertilizers are mined from ore deposits; and potassium-based fertilizers are also mined from ore deposits of "potash".

The importance of this displacement goes beyond economic considerations – in fact, formation of nitrogen fertilizer via the Haber-Bosch process is reportedly so efficient that it removes the economic incentive from reclaiming nitrogen from urine, at least for the present time (Wilsenach and van Loosdrecht 2006). **Resource limitations** is one context. As discussed in Discussion Paper 031-DP-5, phosphorus, in particular, is a finite resource that is receiving notable attention due to dwindling supplies of high-quality phosphate reserves. A second context is **energy**, due to requirements in the extraction/production/transport of commercial fertilizers. Energy is part of the economics, but it also extends to questions of energy security and self-sufficiency. A third context is **climate change**, also related in part to energy, where greenhouse gases are generated/emitted in the manufacture and supply of commercial fertilizers.

Wastewater Treatment Impacts

As illustrated in the following figure, approximately 80% of the nitrogen (N) in domestic wastewater (i.e. in systems without urine separation) originates from urine, the value being about 50% for phosphorus (P) (Maruer et al. 2006; Wilsenach and van Loosdrecht 2006). From a volume perspective, urine comprises only about 1% of the total volume of domestic wastewater.



Relative Fraction of Urine in Domestic Wastewater

In wastewater systems without urine separation, provision of high levels of treatment to limit nutrient discharges to sensitive water bodies comes at a significant capital and operations cost. High operation costs are largely associated with nitrogen removal, where aerobic ammonia oxidation processes require significant energy inputs. These energy inputs are so substantial that urine separation, if implemented to remove wastewater from the main wastewater stream, has the potential to turn a wastewater treatment facility, if also practicing energy recovery from organics, from a net energy consumer to a net energy producer (Wilsenach and van Loosdrecht 2006). This conclusion still applies even if the separated urine is not used as a fertilizer but instead is treated on its own. In this case anaerobic ammonia oxidation (ANAMMOX) processes, which at the current technology development level (i.e. defined as “innovative”, given the few existing full-scale installations) are suitable for concentrated, low-volume waste streams, contribute to significant reduction in overall treatment energy inputs because of much reduced oxygen requirements. Phosphorus recovery from urine, using the crystallization approach described in Discussion Paper 031-DP-5 to produce the slow-release fertilizer magnesium ammonium phosphate (MAP), would form part of this scheme. As discussed in the previous section, energy reduction offers several benefits spanning multiple contexts.

ANAMMOX Reactor System
Source: www.paques.nl

Micro-constituent Control

The majority of ingested pharmaceutical and hormone compounds are excreted from the body in urine and end up in wastewater as part of the class of environmental contaminants or pollutants referred to as micro-constituents (Larsen and Lienert 2007). Many of these compounds have been associated with the potential disruption of endocrine functions in organisms in receiving waters, although the extent and severity of the issue remains unclear at this time (Anderson 2005). Globally, much effort is being expended to better understand this “known unknown”.

The benefit that urine separation may provide in the context of micro-constituent control, specifically related to pharmaceutical and hormone compounds, is governed by several factors. These compounds enter the wastewater stream via routes in addition to urine. Furthermore, for any given ingested compound, the relative fraction of that compound that is excreted in urine will differ from other compounds of interest. However, in broad terms, some researches have speculated that urine separation, if fully implemented, would remove about one-half of the ecotoxicological hazard potential of the main wastewater stream (Larsen and Lienert 2007).

2.2 Technology Development and Application[1]

The CRD Core Area can be described generally as a high population density, urban area that is served by "piped" potable water distribution and wastewater collections systems rather than on-site systems. Thus it is important to consider urine separation technology development and application in this context, rather than those that include rural, low density areas with on-site systems. Further, for this Discussion Paper, the assumption has been made that separated urine would be managed at a utility level (i.e. urine transported to area- or region-wide facilities for subsequent use (fertilizer) or treatment) rather than a household level (i.e. urine applied to home gardens as a fertilizer).

In general, in the context described above, urine separation can largely be considered at an embryonic technology development level. First consider the core of such a system, the **NoMix toilet**. There are several European manufacturers of such fixtures and these models have been used in a variety of pilot projects. Studies completed to date with currently available technology do show favourable results from a public acceptability perspective, and the current toilets work well enough for their continued use in pilot projects so long as users are educated in their use and the fixtures carefully maintained (Larsen and Lienert 2007). However, results obtained from a series of pilot projects suggest that the NoMix toilet technology is immature and requires further development. The challenge is somewhat circular – the industry requires some level of assurance that suitably sizeable markets will exist to justify the investment in technology development, but that conclusion has not yet been confirmed.

The **transport** of separated urine from the toilet to a central location has been described as "... the *key* problem" (Larsen and Lienert 2007). Options include transport from local storage tanks (i.e. located at the residence or building) using tanker trucks, a dedicated pipe system, and the existing sewer system. The latter option would see urine batch-transported via the sewer system at night,

[1]This section was prepared using information from two main sources, the first being the aforementioned Eawag organization from Switzerland (Larsen and Lienert 2007). Their trans-disciplinary research project on urine separation, Novaquatis, was conducted over 2000 to 2006. Within this project, numerous studies conducted within eight research programs addressed a wide variety of topics ranging from public acceptability to technical to pilot program implementation. The comprehensive Novaquatis project produced over 60 publications, primarily in international, peer reviewed journals and conference proceedings. The second main information source was EcoSanRes (Kvarnström et al 2006), which is an international research and development programme sponsored by the Swedish International Development Cooperation Agency and aligned with the Stockholm Environment Institute. EcoSanRes's work summarizes topic-related literature and provides information on examples from Swedish municipalities.

over a very short duration, when the wastewater flows are very low. All options have advantages and disadvantages, as well as risks, when viewed through a triple bottom line lens of environmental, social and economic perspectives. However, like dual plumbing and distribution systems to maximize the re-use of reclaimed water, as discussed in Discussion Paper 031-DP-7, new developments may provide the greatest opportunity for urine separation implementation. In this scenario the construction of dedicated pipe systems in new developments to convey urine may be the most practical and lowest risk approach.

Once collected and transported to central locations, the urine requires **processing** to enable either (i) its direct **use** as a fertilizer or (ii) to extract nitrogen and phosphorus (i.e. nutrients) from the urine, for use as fertilizer, and **treat** the remaining fractions such they can be returned to the environment safely.

With respect to (i), large-scale agricultural use of urine in Sweden has not met any difficult practical problems, attributed to the common use of animal urine as a fertilizer (Kvarnström et al 2006). In addition, field studies conducted in both Sweden (Kvarnström et al 2006) and Switzerland (Larsen and Lienert 2007) have confirmed that urine and urine-based fertilizers are generally comparable to artificial, commercial fertilizers in terms of agricultural performance. However, urine storage, quality control, certification and buyers of grain have been key issues in Sweden. The need for a certification system for urine application in agriculture, similar to that implemented for composted household wastes, is recognized as a key way to simplify the use of household urine in Swedish agriculture. Proposed Swedish legislation regarding the agricultural use of urine collected from multiple households sets requirements for urine stabilization based on pH (minimum pH = 8.8), storage temperature and storage time – here the intent is pathogen reduction. Alternatively, public acceptance and agriculture sector surveys conducted in Switzerland found that both groups emphasized that it was essential to eliminate any risks, including those potentially posed by micro-constituents (Larsen and Lienert 2007). This finding suggests that urine would need to be further treated, beyond stabilization afforded by storage or biological processes (i.e. conversion of urea to ammonia and nitrate), to address micro-constituent levels. Nanofiltration and ozonation processes have been found to significantly reduce micro-constituent levels (e.g. 50 to 99% removal of compounds studies), but these results were obtained from laboratory-scale studies and should be considered preliminary results at this time. Furthermore, since risks cannot be eliminated completely, ecotoxicological studies accompanied by broader social debate, with elaborate approval procedures, were suggested as means to address this issue.

Scenario (ii) would see phosphorus and nitrogen recovered from urine as described in Section 2.1 (Wastewater Treatment Impacts). These facilities could be located on the same site as the municipal wastewater treatment facility. In this situation, the residual liquid-stream from the nutrient recovery system would be directed to the municipal WWTF for co-treatment and disposal/reuse with the main wastewater stream (Wilsenach and van Loosdrecht 2006). While this scheme is technically feasible, at present it exists as an idea that has yet to be implemented at full-scale. The fertilizer product (MAP) recovered from urine, via crystallization, has been found to be almost free of measured micro-constituents (Larsen and Lienert 2007). Again, this conclusion is based on limited study and should be considered preliminary at this time.

3 Reuse Potential

3.1 Unit Basis

Nitrogen is the most abundant plant nutrient available in urine and thus it has been used for the illustration purposes of this Discussion Paper. Discussion Paper 031-DP-5 specifically discusses phosphorus recovery from wastewater, under the assumption that urine is contained in the main wastewater stream.

People generate between 2.6 and 4.0 kg N/yr-p of urine-based nitrogen on an annual basis (Kujawa-Roeleveld and Zeeman et al. 2006). For illustration purposes, it has been assumed that urine could be directly land applied, once per year, following a six month stabilization/storage period and micro-constituent removal, as described under point (i) in Section 2.2. Therefore, urine would be collected for one-half the year for subsequent use in the second half of the year. Ammonia nitrogen is volatile, which would result in some loss of available nitrogen to the atmosphere during the storage period. Assuming a typical urine-based nitrogen generation rate of 3.5 kg N/yr-p, prorated for a six month period and a 20% nitrogen loss during storage, yields a unit generation rate of 1.4 kg N/yr-p. Finally, not all urine can be practically separated from wastewater, in part due to the efficiency of NoMix toilets (Larsen and Lienert 2007). Assuming a 75% urine separation efficiency, the unit generation rate becomes 1.1 kg N/yr-p.

Plant / crop nitrogen requirements vary widely, depending on site fertility and crop yield as well as various nitrogen transformations (e.g. volatilization, denitrifcation) once fertilizer is applied. The range in values could span 100 to 400 kg N/ha-yr in British Columbia (McDougal et al. 2002). For illustration purposes the analysis assumes a mid-range value 200 kg N/ha-yr.

3.2 Regional Potential

The potential amount of N that could be recovered from source-separated urine generated within the CRD, in the context of the Core Area Wastewater Management Program, will depend on the population, urine N levels and the efficiency of urine separation.

Given the current embryonic level of urine separation concept and technology development, the analysis assumes that urine separation could be practically implemented in the medium-term (Year 2030) to long-term horizon (Year 2065) once the approach matures and issues are satisfactorily addressed. In this scenario, new development to accommodate the incremental residential population between Year 2030 and 2065 could provide urine separation systems. The increase in residential population between Years 2030 and 2065 is estimated to be about 86,000 people. Applying the 1.1 kg N/yr-p unit urine generation rate to this incremental population gives an annual urine-based N generation rate of about 95 t N/yr in Year 2065. Based on the assumed 200 kg

N/ha-yr land application rate for agriculture, the urine would provide the nitrogen requirement for 475 ha of farmed land.

In Canada in 2007, commercially manufactured ammonia nitrate fertilizers cost approximately $1,350/t when expressed on an N basis (University of Guelph 2007). In today's dollars, the separated urine generated in Year 2065 would have a value of $128,000 in terms of off-set commercial fertilizer. This low value is expected given current experience elsewhere, but does not capture the energy and greenhouse gas benefits described in Section 2.1.

4 Summary

Incorporation of urine separation into regional wastewater management systems represents a fundamental shift in approach – the beginnings of the separation of the individual streams that comprise wastewater at their source. The current state of concept and technology development, whether commercial products (e.g. toilets) at the user level, system integration at a regional utility level, or specific elements of the system (e.g. treatment), is largely at an "embryonic" stage limited to laboratory- of pilot-scale study. This situation suggests that urine separation is a longer-term prospect for the CRD. However, significant benefits provided by urine separation will certainly drive innovation within the wastewater industry over the coming decades. The CRD's pursuit of a distributed wastewater management strategy, and in particular the use of this strategy to accommodate future community growth, will provide the District with flexibility to adopt and integrate urine separation as developing concepts and technologies allow.

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