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Sustainable engineering of sewers and sewage treatment plants for scenarios with urine diversion

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Abstract

Urine diversion (UD) has been studied for decades as a way to enable distributed sanitation and to recycle nutrients onto land to fuel circular economies. No study to date has attempted a quantitative technical and economic analysis of the downstream effects of UD on sewage transport and treatment. This work used the SeweX model to reveal for the first time that through UD, hydrogen sulfide concentration in sewer headspaces can be reduced, and consequently sewer corrosion can be reduced. For a long rising main of 5 km, sewer headspace H_2S can be reduced from 280 ppm to 200 ppm by diverting 75% of the urine. The same scenario enables the reduction of sewer corrosion from 12 to 10 mm/yr. Modelling sewage treatment plants with BioWin showed that sewage treatment responds to UD with a sharp reduction of the anoxic volume and a decrease of energy requirement by up to 50% at 75% UD. An upgrade of bioreactors to increase capacity by 20% can be completely avoided

if 7% of the catchment's urine is diverted. Reductions in upgrade expenditure by up to 75% can provide the economic incentive for the uptake of UD.

Keywords: sewage treatment plant, sewer modelling, wastewater management, urine diversion

1. Introduction

The United Nations sustainable development goals include water and sanitation for all (Goal 6). Larsen et al. (2016) highlighted that only 80% of the world population has access to improved sanitation, and that to make sewage removal and treatment available to the world's poor, new paradigms need to arise, including the development of non-sewered sanitation options (Capodaglio et al., 2016). These include the use of source separation of wastewater fractions, as well as decentralised (at precinct level) and distributed (at building level) treatment.

Urine separation at the source has been highlighted for decades as a promising solution for non-sewered systems. Urine accounts for only < 1% of domestic wastewater flow, but comprises 80% of total nitrogen (TN), 50% of total phosphorus (TP) and 65% of potassium (K^+) (Ledezma et al., 2017). Collecting and treating urine at the source can simplify treatment of the other fractions (Larsen and Maurer, 2011), such as brown water (faeces and toilet paper) and greywater (water from showers, laundries and kitchens). It can also improve resource recovery efficiency in urban water systems (Capodaglio, 2020), and reduce their overall energy demand (Capodaglio and Olsson, 2020).

While urine diversion (UD) has been the focus of research and development for the developing world, it can also be applicable to high-income settings which are already serviced by sewers and sewage treatment plants. In fact, we argue in this paper that this is where its applications may arise first, due to a number of factors that are concomitantly contributing to an urgency for change by wastewater utilities in large modern cities. In particular, three factors have emerged in recent years (Manning et al., 2016): (1) wastewater infrastructure is typically over 50 years old and is approaching end of life; (2) urban populations are increasing and they are becoming increasingly dense, thus intensifying pressure on existing infrastructure (e.g., greater Melbourne is projected to grow from 5 to 9 million in the next 40 years); (3) legislation is imposing increasingly stringent regulations on treated effluent discharge, especially for total nitrogen (TN), as a way to protect receiving water bodies from eutrophication. To increase pressure on regulatory authorities, the United Nations Environment Programme's (UNEP) released the Colombo declaration (October 2019), revealing its goal to cut nitrogen discharge in half over the next 10 years (UN Environment, 2019). These three factors imply that major investments will be required in the coming decades to replace and upgrade wastewater infrastructure.

However, the facts that regulations are becoming more stringent and that future trends in urban population densities are uncertain, make investment particularly risky. If a city replaces its sewage treatment systems with the same century-old technologies that are in use today and that have a life span of around 50 years, it may during the next decade or two face the need to make further investments, to address potential inadequacies of these technology in their ability to handle dynamic urban change and tightening regulations on effluent quality. Here is where a distributed solution like UD may be ideal, as it can be implemented stepwise, in conjunction with population trajectories, and hence it will naturally be able to handle the uncertainty and dynamicity of urban trends, to deliver more flexible and resilient solutions. It will also help reduce local nitrogen emissions and thus meet TN targets, as urine alone comprises 80% of nitrogen in urban sewer systems. Furthermore, source separation may favour the adoption of fit-for-purpose wastewater treatment and reuse, with important implications for water security (Capodaglio, 2020).

Technologies for the treatment of source-separated urine are well-researched, and studies have proven the technical feasibility of diverse solutions such as electrodialysis (De Paepe et al., 2018; Pronk et al., 2006), microbial electro-concentration (Freguia et al., 2019), biological oxidation and distillation (Udert and Wächter, 2012) for the conversion of urine into safe products which see future opportunities in the fertiliser markets. These technologies are still being optimised and their costs for the purpose of producing renewable fertilisers are not available in the literature. Similarly, there is no agreement on the likely price range of urine-derived fertilisers. Therefore, a full economic analysis for urine diversion is not possible until urine processing technologies are further developed and optimised.

This study's focus is therefore limited to the downstream effects of UD on existing infrastructure (sewers and sewage treatment plants, STPs). Previous work by Wilsenach and Van Loosdrecht (2003, 2004; 2006) has already revealed through modelling that UD can deliver significant benefits in the design and operation of STPs, by diverting nitrogen loads. More recently, the work of Hilton et al. (2021) revealed through life cycle assessment that urine diversion (at 70%) performs better than centralised treatment on a number of parameters, including energy demand, global warming potential and freshwater use. However, no economic analysis has been done so far to form the basis of a business model for UD. Also, no work to date has been published on the effect of UD on sewers.

Sewer corrosion is caused by sulfate reduction to sulfide in rising mains, followed by volatilisation in gravity sewers and subsequent oxidation to sulfuric acid on the concrete wall exposed to air (Boon, 1995; Hvitved-Jacobsen et al., 2013). There have been several studies on sewer corrosion (Roberts et al., 2002; Wells and Melchers, 2014) and a number of different control measures ranging from the surface washing (Sun et al., 2016), crown spraying (Sydney et al. 2016) to chemical dosing to sewer (Aesoy et al., 2002). However, these measures significantly add the capital investment as well as the operational cost to the management of urban sewer systems. Hence, the preventive measures for corrosion control become more attractive.

In cities where drinking water production uses ferric chloride instead of alum, the contribution of bodily waste to total sulfate is approximately 80% (Pikaar et al., 2014). Urine accounts for ~70% of sulfate in human bodily waste (the remaining 30% being in faeces), making it the most important contributor to sulfate in sewers. However, urine also strongly contributes to the alkalinity of sewers, mostly through its free ammonia and bicarbonate content. Its diversion could therefore cause lower pH in the sewer, with multiple effects on the processes occurring therein, including biological activity and hydrogen sulfide speciation and vapour-liquid equilibrium. An in-depth computational model is required to calculate the concentrations of H_2S in the sewer headspace at different rates of UD.

In this work, we aimed to quantify the effects of UD on sewer corrosion, and on the design and costs of sewage treatment plant upgrades. We also exhibit how UD can assist existing STPs in coping with increasing loads of pollutants and increasingly stringent discharge regulations. In particular, we quantified the effects of urine separation on sewer odour and corrosion potential, and on the costs of upgrading sewage treatment plants when population in their catchments increase. Our models predict a slight decrease in corrosion rates, and a substantial reduction of upgrade costs for treatment plants, when a fraction of urine is diverted from the sewer network.

2. Materials and Methods

2.1. Sewage and urine composition

A baseline sewage flow composition was determined using the following per capita loads (Butler et al., 1995), which were adapted for typical Australian cities (EP = population equivalent): wastewater production 170 L/d; total Kjeldal nitrogen (TKN) 12 g EP^{-1} d^{-1}; total phosphorus (TP) 1.5 g EP^{-1} d^{-1}; chemical oxygen demand (COD) 125 g EP^{-1} d^{-1}; biochemical oxygen demand (BOD) 52 g EP^{-1} d^{-1}; total suspended solids (TSS) 60 g EP^{-1} d^{-1}; volatile suspended solids (VSS) 54 g EP^{-1} d^{-1}; total alkalinity as $CaCO_3$ 65 g EP^{-1} d^{-1}.

Urine composition was determined using the average of nine samples of hydrolysed urine collected from temporary waterless urinals at the male toilet at the Advanced Water Management Centre, University of Queensland (UQ Sub-Committee for Human Research Ethics approval 2019000024). Average characteristics are as follows: flow per person 1.2 L EP^{-1} d^{-1} (Larsen and Maurer, 2011); TN 8,000 mg L^{-1}; TP 500 mg L^{-1}; SO_4^{2-} 2,190 mg L^{-1}; total inorganic carbon 3,850 mg L^{-1}; alkalinity 26,750 mg $CaCO_3$ L^{-1}; acetate 3,200 mg L^{-1}.

2.2. Assessment of sewer headspace H_2S and corrosion rates with SeweX

A virtual sewer system representing a typical Australian sewer, consisting of a single rising main discharging into a gravity sewer pipe was modelled in this study. The length of the rising main (600 mm diameter) was varied from 1.0 km to 5.0 km, and that of the gravity sewer (800 mm diameter) was kept constant at 1.0 km. Wastewater temperature was assumed to be 28°C in the model, representative of hot climates and a worst case scenario for H_2S evolution. The extent of hydrogen sulfide production in rising main depends upon its length, and this in turn affects the H_2S concentration in the headspace of the gravity sewer receiving the rising main discharge. As such, different lengths of rising main will be impacted differently for the same change in sewage characteristics due to the UD in the catchment.

The flow to the sewer system was estimated based on the population of 20,000 and per capita wastewater production of 170 L.day^{-1} for the baseline case (without UD). Typical wet-well dimensions and the pump capacity of 300 L.s^{-1} were used to determine the flow pattern in the rising main sewer. The hydraulic data for the gravity sewer pipe was obtained from a hydraulic model of the sewer system developed using EPA SWMM model. The air velocity in sewer headspace was assumed to be 50% of the water velocity. The wastewater characteristics were determined by considering the normal domestic sewage characteristics (data collected from different sewer systems in Australia) and making adjustments for changes in sulfate, volatile fatty acids (VFA), ammonia, phosphate and carbonate concentrations due to UD.

The impact of changes in sewage composition due to UD on sulfide production in sewers and resulting concrete corrosion potential was investigated through a model-based study using the SeweX model, a model that has been widely used for predicting sulfide production in sewers (Pikaar et al., 2014; Sharma et al., 2013, 2008a, 2008b). The SeweX model takes into account the biochemical processes (carbon, sulfur and nitrogen conversions under aerobic, anaerobic and anoxic conditions) occurring in sewer biofilms and in the bulk liquid, chemical processes and equilibrium reactions (e.g. sulfide oxidation, precipitation reactions, and acid-base systems) and physical processes (such as liquid-gas mass transfer), and predicts both the temporal and spatial variations of wastewater composition, including sulfate, sulfide, pH, and VFAs. The pH prediction in the model is done based on the charge balances (Sharma et al., 2013). Sewer system characteristics (network configuration, pipe size, length and slope), sewage characteristics and hydraulic properties are used as the inputs. The SeweX model, that has previously been calibrated for a sewer network conveying domestic sewage (Sharma et al., 2008b) was used in simulations in this study.

The concrete corrosion rates were estimated using the expression proposed by Wells and Melchers (2015). The relative humidity was assumed to be 95% and air temperature of 28°C was considered in the calculations.

2.3. Design of sewage treatment plants using Biowin

The simulation software Biowin was used to design sewage treatment processes, according to the modified Lutzak-Ettinger (MLE) and 4-stage Bardenpho (4BPO) configurations. The flow diagrams for both configurations are shown in Fig. S1. As nitrogen controls the size and energy consumption of treatment plants, this study focusses mainly on the effects of nitrogen on STP design, hence anaerobic stages (typically included to support the growth of polyphosphate-accumulating organisms) were not included to enable simpler interpretation of results. Both configurations were set up without primary settling tanks (PSTs), as this is the more common scenario in Australian sewage treatment plants. A summary of input parameters (wastewater fractions and kinetic parameters) for the Biowin runs is given in the Supplementary Information, Tables S1 and S2. The influent composition was calculated for each scenario of UD based on the above sewage and urine loads and concentrations. The simulation was run at steady state and using the daily average dry weather influent flows and compositions. The wastewater temperature was set to 20 ºC, the typical yearly average temperature of sewage at the treatment plants in southern Australia. The mixed liquor suspended solids (MLSS) was fixed at 3.5 g/L, and effluent TN targets were set to 7 mg/L for MLE and 4.5 mg/L for 4BPO. Sludge treatment was not included in the model, therefore the effect of return liquors was also not considered, in the view that these side streams should be treated for full nutrient removal/recovery rather than being sent back to the head of the plant.

2.4. STP upgrade cost analysis

Both capital and operating costs were estimated for sewage treatment plant upgrades. The only assets that were costed are bioreactors, recirculation pumps and blowers, as these are the ones that are affected by nitrogen loads. The aim here is a comparison between different urine diverted fractions, and any asset whose size is primarily dependent on flow rather than nitrogen concentration (e.g. final settling tanks) would be upgraded irrespectively of UD. Bioreactor costs were estimated in Australian dollars based on the cost compilation by Young et al. (2012) and economies of scale as reported in Larsen and Maurer (2011). The currency conversion was based on the date of publication of Young et al. (2012). The resulting equation 1 was used to estimate bioreactor capital costs:

$$Bioreactor\ capital\ cost = AU\$3{,}200 \cdot EP^{0.725} \tag{1}$$

The capital costs of blowers and pumps were estimated using adjusted historical costs. The operating cost items that are affected by UD are electricity (for blowers and pumps) and sludge handling and removal from the site. The net present value of operating costs was calculated using a design horizon of 30 years and a discount rate of 4.55%. The cost for electricity was set to AU$0.13/kWh. Other assumptions around these operating costs include: pump and blower efficiency of 60%, pumping head of 7 m, sludge transport cost of AU$0.2 per wet tonne per km, sludge dry solid content of 12%.

3. Results and discussion

3.1. Effects of UD on sewer operation

The SeweX model was run using varying lengths of sewer mains (1-5 km) and a fixed-length gravity sewer (1 km), at a range of urine diversion from 0 to 75%. Fig. 1 shows that, for the longest rising main considered, dissolved sulfide concentration at the end of the rising main is reduced by up to 25% with UD, and that headspace H_2S concentration at the end of the gravity sewer follows a similar trend. The reductions in sulfide production and emission is roughly proportional to the fraction of urine being diverted, and the effect is more pronounced for longer rising mains, reflecting the fact that the sulfide production is controlled by the hydraulic retention time in the rising main. The effects of UD relevant to the production and emission of sulfide in sewer are lower pH, lower alkalinity, and lower sulfate and VFA concentrations in the wastewater, the extent of change being proportional to the fraction of urine diverted. The pH of sewage at the source decreases from 7.0 to 6.6 from 0% to 75% UD, solely due to the reduced alkalinity. The pH decreases further as the sewage moves along a rising main, due to the biological reactions forming sulfide and volatile fatty acids, which consume wastewater alkalinity. The differences between the different UD fractions are smaller for longer rising mains as the pH at the source is already lower and any further change in the wastewater composition has minimum impacts.

The decrease in pH would impact the biological activity negatively due to pH inhibiting effects (Sharma et al., 2014). This together with the lower sulfate and lower VFA concentrations would result in reduced sulfide production in rising main, especially in very long rising mains. On the other hand, the decrease in pH should result in enhanced H_2S emission as higher fraction of dissolved sulfide exists as the unionized form of sulfide (H_2S) provided that the concentration of sulfide remains the same. However, the results have shown that, despite some decrease in pH, the headspace H_2S concentration at the end of gravity sewer showed a decreasing trend at the increasing diverted fractions. This clearly shows that the decrease in the dissolved sulfide concentration at the end of rising main had more pronounced impact than that of the change in the wastewater pH.

The sulfate, which serves as the substrate for sulfate reducing bacteria responsible for sulfide production, tends to become limiting for longer rising mains and hence the extent of UD and resulting decrease in sulfate concentration shows more pronounced impacts on sulfide production for a longer rising main.

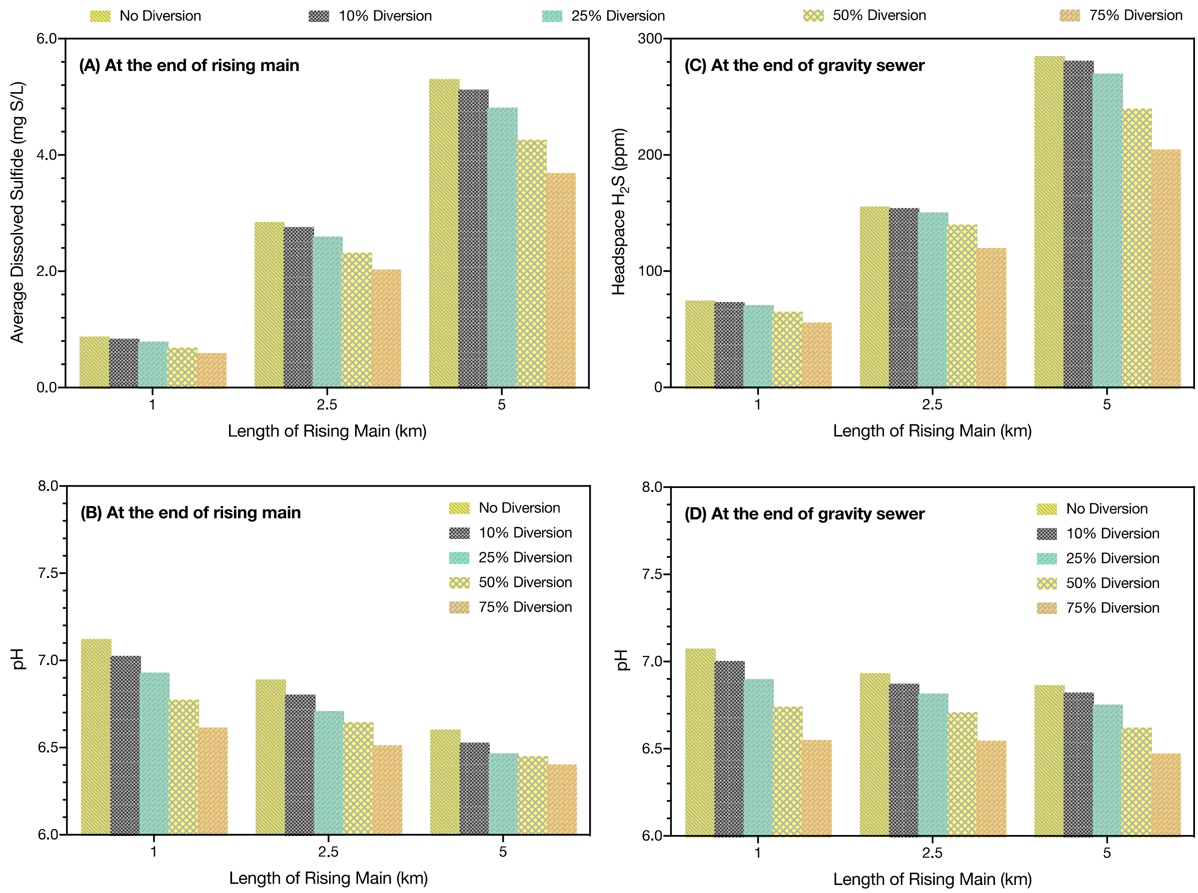

Figure 1. Simulation results showing: (A) dissolved sulfide at the end of rising main; (B) pH at the end of rising main; (C) headspace H2S at the end of gravity sewer; and (D) pH at the end of gravity sewer

As described in the materials and methods, the impacts of changes in H_2S concentration in sewer headspace were investigated in terms of concrete corrosion rates. Figure 2 reveals that the predicted corrosion rate is lower at increasing UD. The effect on corrosion rate is less evident than the effect on H_2S concentration as the corrosion is proportional to the square root of the headspace H_2S concentration.

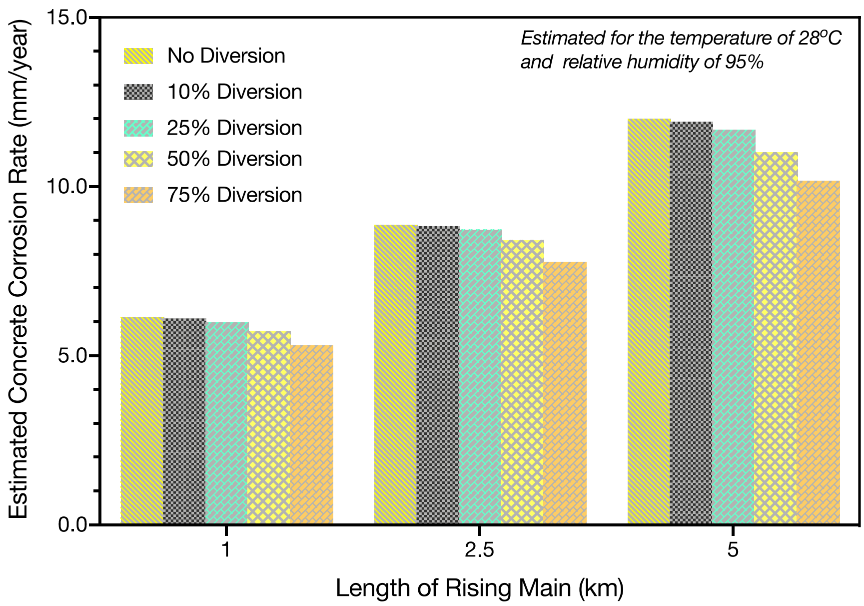

Figure 2. Impacts of UD on the corrosion rate of concrete pipes

3.2. Effects of UD on sewage treatment plant design

At a given population equivalent (EP, 1 million used as baseline), the way a sewage treatment plant is designed changes significantly with the fraction of urine that is diverted (Fig. 3). At fixed MLSS of 3,500 mg/L and capped target effluent TN (at 7 mg/L for MLE, and 4.5 mg/L for 4-stage BPO), the aerobic-to-anoxic recycle (also known as the a-recycle) naturally decrease with the influent TKN following the nitrogen mass balance, and aerobic-anoxic recycle becomes unnecessary at high UD above 70%, whereby all nitrogen is removed by assimilation in aerobic biomass. The anoxic tank requirements shrink as the urine diverted fraction increases, with no anoxic stage required at diversions higher than 50% (the fraction will be pushed upwards if sludge digestion side streams are returned to the mainstream). The reduction in anoxic tank size is linked to an increase in denitrification rates, due to an increase in the readily biodegradable COD (rbCOD) in the anoxic tank. The latter has two causes: (1) the reduced NO_3-N loads in the a-recycle stream, and (2) the decreased a-recycle flow, which reduces the dilution effect on incoming rbCOD. As a consequence, the anoxic sludge age (or solid retention time, SRT) in both the MLE and 4BPO configurations, is reduced and the non-aerated fraction progressively decreases from 47-50% for the baseline scenario with no UD, to 8-12% and 0% for 50% and 75% UD, respectively. The total bioreactor volume is reduced accordingly, and the aerobic zones roughly remain unchanged. It is worth noting that the steepest changes in SRT and bioreactor volume are at low UD fractions, which implies that minor interventions on urine source separation in urban catchments can lead to significant benefits in sewage treatment plant size and operation. At low diversion fractions (< 20%), a bioreactor volume reduction of ~1.5% for each percent point diversion of urine is predicted by the model.

As summarised in Table 1, power consumption also dramatically decreases with increasing UD, as a consequence of the reduced nitrogen loads. Both aeration and pumping contribute to the reduction of power consumption. Total electricity consumption for aeration and pumping (per cubic metre of wastewater) drops from 0.71 to 0.26 kWh m^{-3} (MLE), and from 0.60 to 0.28 kWh m^{-3} (4BPO), from the base case to 75% UD.

Sludge production is almost unaffected and only slightly increased with UD, as more BOD is oxidised aerobically rather than anoxically, with increased biomass production compared to anoxic growth. External carbon addition was not required in the 4BPO configuration, whereby endogenous production was sufficient for secondary denitrification at the average flows and concentrations used for the steady-state simulation. However, this may not be the case at daily peak load conditions, which were not analysed in this work.

Interestingly, effluent TN values were set to be capped, but for both the MLE and 4BPO cases, the effluent TN sharply drops to 2-3 mg/L as UD hits 75%, and the anoxic stage is no longer required. Total phosphorus (TP) was not set as a target in this analysis, but its values in the effluent decrease with UD as the influent P-loads are decreased, and effluent targets for P may be met without a dedicated anaerobic stage when UD is high.

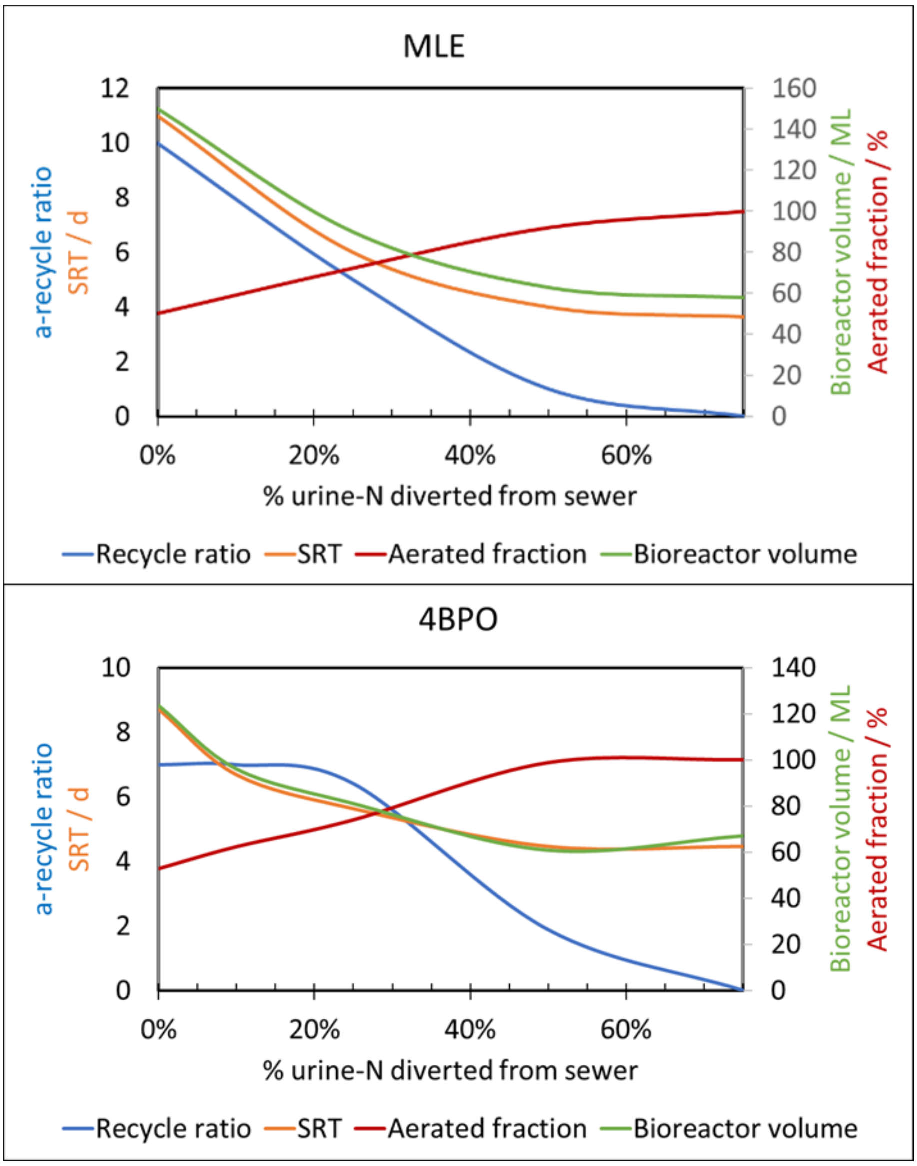

Figure 3. Effect of urine diverted fraction on operating parameters of sewage treatment plants (1m EP), for MLE configuration (above) and 4-stage Bardenpho configuration (below). MLSS = 3,500 mg/L, effluent TN target of 7 mg/L (MLE) and 4.5 mg/L (4BPO). The required bioreactor volume drops sharply at low urine diverted fractions, until the aerated fraction approaches 100% at approximately 50% UD, and beyond that no further benefits are evident. The bioreactor volume closely follows the sludge age (SRT).

Table 1. Design and operating parameters for sewage treatment plants under MLE and 4BPO configurations, for urine diverted fractions of 0-75%.

		MLE				4BPO			
% UD		0%	25%	50%	75%	0%	25%	50%	75%
HRT	H	21.2	12.7	8.9	8.2	17.4	11.4	8.6	9.5
SRT	D	11.0	6.0	4.0	3.6	8.7	5.6	4.5	4.5
a-recycle ratio		10	5	1	0	7	6.4	1.9	0
Pumping power	kWh m^{-3}	0.35	0.19	0.06	0.03	0.25	0.24	0.09	0.03
Aeration power	kWh m^{-3}	0.36	0.31	0.27	0.23	0.34	0.31	0.27	0.25
Sludge production	kg VSS EP^{-1} d^{-1}	46.6	50.5	53.3	54.0	48.4	49.0	51.7	51.6
Effluent TN	mg/L	7.3	7.3	7.3	2.5	4.5	4.5	4.5	2.3
Effluent TP	mg/L	3.3	2.7	2.1	2.1	3.8	2.7	1.6	0.7
Effluent BOD	mg/L	3.0	3.4	3.9	4.5	3.2	3.5	3.6	4.4
(Primary) anoxic tank HRT	H	10.6	3.5	0.7	0	4.2	2.0	0.35	0
(Primary) aerobic tank HRT	H	10.6	9.2	8.2	8.2	8.5	7.8	7.8	9.5
(Secondary) anoxic tank HRT	H	n/a	n/a	n/a	n/a	4.0	1.0	0.7	0
(Secondary) aerobic tank HRT	H	n/a	n/a	n/a	n/a	0.7	0.7	0.7	0

3.3. Design and cost of a sewage treatment plant upgrade

When a sewage treatment plant reaches its capacity in a situation of growing population and/or increasingly stringent discharge regulations, additional bioreactors, recirculation pumps and blowers need to be installed to meet the new demand. However, if a fraction of urine is diverted from sewers, the existing capacity may be able to handle the increasing loads. Fig. 4 shows the total bioreactor volume requirement and total electrical power demand for treatment of a sewage stream for a baseline of 1 m EP, and for the increased load scenarios of 1.2 m, 1.5 m and 2.0 m EP, with a 4BPO system. Assuming that current operation at 1m EP is based on no UD, the graph enables the visualisation of the fractions of UD that would be required to meet discharge requirements with the existing bioreactor volume at different population equivalents. For example, if the STP catchment is forecast to increase from 1m to 1.2 m EP, no additional bioreactor volume is needed if 7% of the urine is diverted. A diversion of 23% is needed to accommodate an increase to 1.5 m EP, and one of 47% to double capacity to 2 m EP. However, it can be seen that the electricity requirement is not met at the new design conditions, and an upgrade of recirculation pumps and blowers will still be required. A much higher fraction of diverted urine would be required to avoid increasing power requirement in the upgrade design: for an upgrade to 1.2 m EP, a UD of ~35% would be needed.

The overall effect on the costs of an upgrade is shown in Fig. 5, where a flat UD fraction of 50% was used. For example, a capacity increase of 200,000 EP (20%) will cost $42 m without UD. With UD, the same capacity increase will lead instead to a net cost reduction of $24 m due to the reduction of electricity requirements. The net saving is therefore $66 m, equivalent to $55 per total EP, or $330 per additional EP. These savings are progressively diminishing as the upgrade is increased in size: $165 per additional EP for an upgrade of 0.5 m EP (50%), and $110 per additional EP for an upgrade of 1.0 m EP (100%). The respective savings in a greenfield scenario (i.e. where an STP is built ex novo as part of a new development) are shown in the Supporting Information, Fig. S1. These numbers are important because a business model could be set up to allow those savings to be used to cover the costs of onsite urine collection and treatment, and thus they set an upper boundary for the costs of these technologies (although any end-product such as fertilisers directly produced from the collected urine will further offset the costs). These cost savings will benefit wastewater utilities and can be used to enable the shift from centralised wastewater treatment to more flexible and adaptable solutions, such as urine diversion and onsite treatment. The savings can also be used to incentivise the necessary uptake of urine-derived fertilisers for agriculture and horticulture, as well as the inclusion of urine diversion capacity in the design of new buildings.

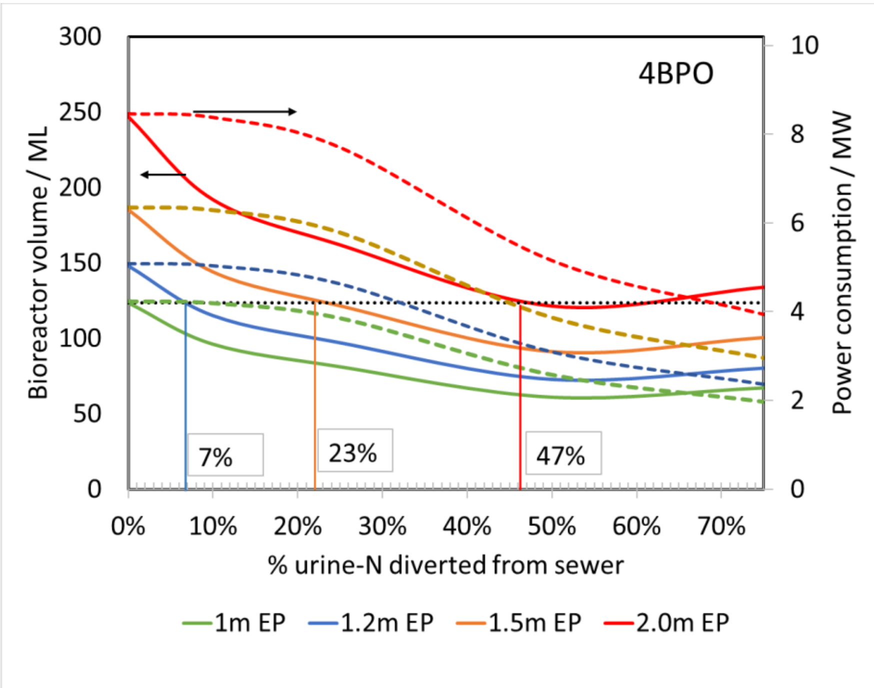

Figure 4. Graphic calculation of the effect of UD fractions on plant capacity, for a pre-existing STP of 1m EP, based on the 4-stage Bardempho configuration. Solid lines are bioreactor volume requirements (ML), dashed lines are energy consumptions in MW. Horizontal dotted line: pre-existing bioreactor volume (and power consumption). The intersections between the solid lines and the horizontal dotted line indicate the plant's new capacities and the UD fractions required to achieve them without upgrading the existing bioreactor. Electrical capacity and related equipment will need to be upgraded as UD alone does not sufficiently reduce power consumption.

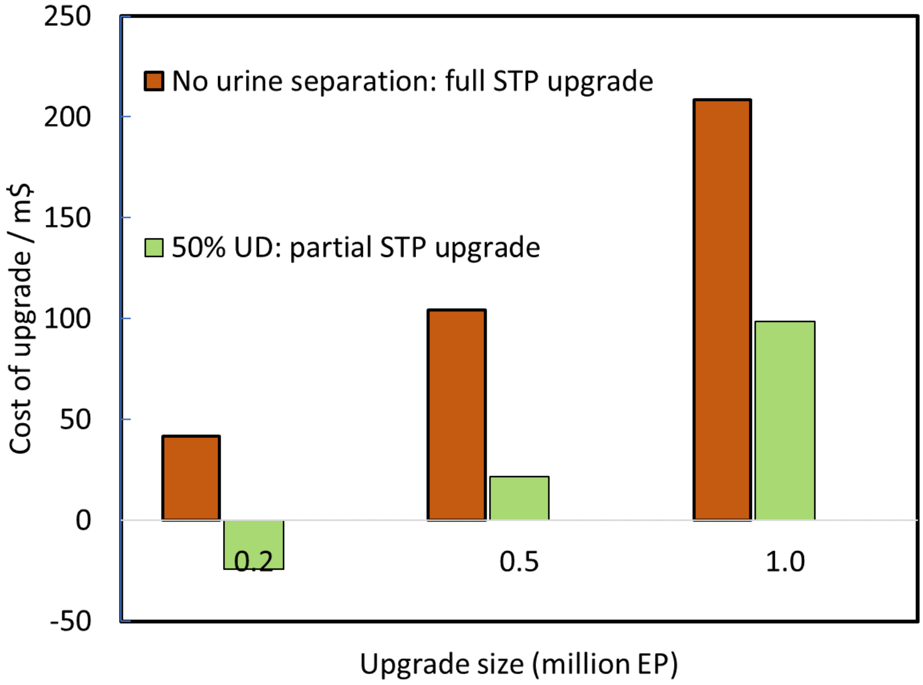

Figure 5. Urine-dependent costs (capital and operating) for a sewage treatment plant upgrade from a baseline of 1m EP, 4BPO configuration. Brown columns indicate the costs for a full upgrade, green columns are the costs for the upgrade when 50% urine diversion is applied. The upgrades required when UD is implemented are limited to blowers and pump capacity increases, and additional electricity requirements.

4. Conclusions

In this work, we modelled the effects of urine diversion on sewer processes and sewage treatment plant design and operation, using two broadly accepted modelling tools, the SeweX model and Biowin. The results reveal that urine diversion can significantly reduce the headspace H_2S concentrations in gravity sewers, from 280 ppm at 0% diversion, to 200 ppm at 75% diversion. This results in reduced concrete corrosion rates from 12 mm/yr to 10 mm/yr. In sewage treatment plants, urine diversion leads to a substantial reduction of the electricity requirements by >50% (at 75% diversion), as well as reduced requirements for anoxic zone volumes (they become unnecessary at diversions > 50%), which lead to the potential of capacity increases without the need for bioreactor upgrades: a diversion of 7% of a catchment's urine leads to the ability to process sewage from an additional 20% population, without the need to upgrade bioreactors. This leads to opportunities for decentralisation of wastewater services in modern cities, where wastewater treatment infrastructure is at capacity and will require upgrades in the near future.

5. Acknowledgements

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