Supplementary Materials

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Supplementary 1. Use pattern over time

Electronic recording of the number of users per day over time are shown in figure S1. The periodic pattern of the week with Sunday being the day with lowest number of uses is visible. In closed loop, there are additional short periods with zero use, corresponding to period of system maintenance.

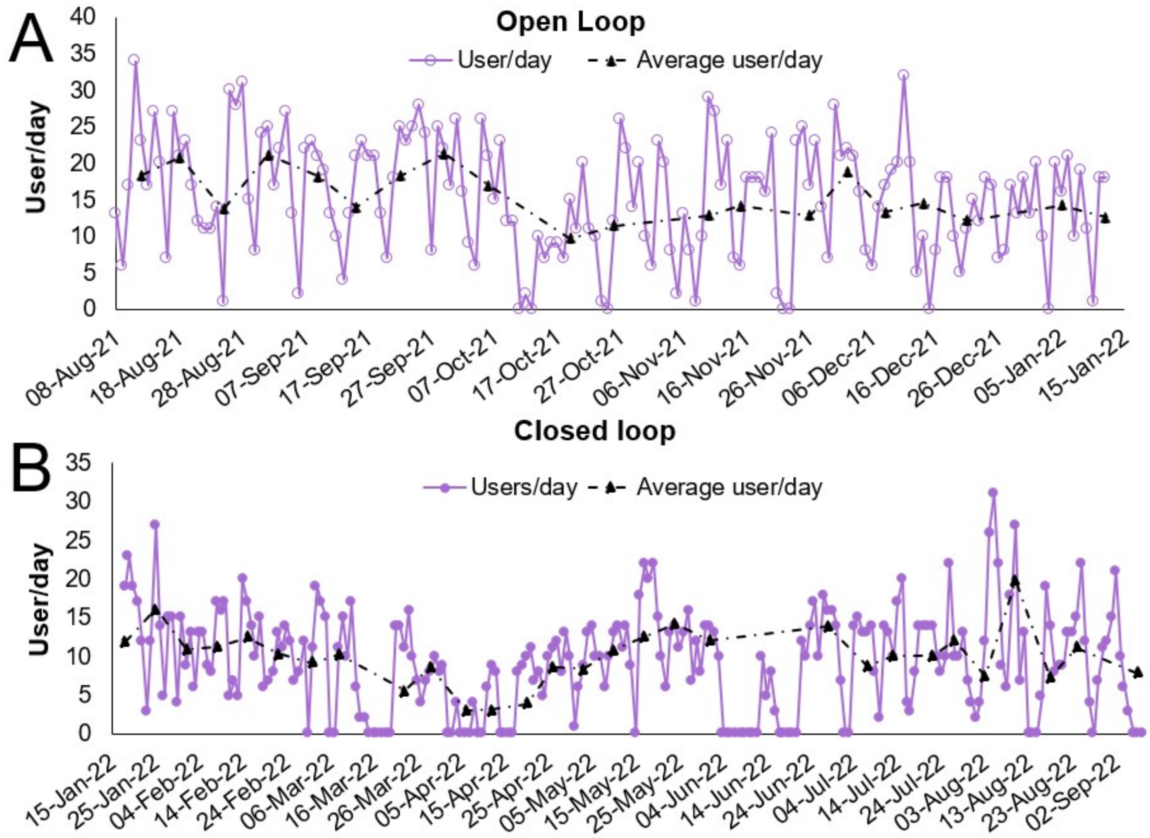

Figure S1 Pattern of toilet use over time in A .Open loop and B. Closed loop. The periodic nature of the user dips reflect a decline in visitors at the test site on Sundays. Black dashed line represents the weekly average

Supplementary 2. Water use analysis

Tracking of water consumed and recycled was enabled by the combination of a water meter and electronically actuated dispensing of water in the e-toilet.

Water consumption inside the e-toilet occurs across four functions: cistern flush, floor wash, personal wash, and handwashing. Cistern flush and floor wash are carried out through timed opening of valves thus have a programmed volume; the online use portal records the number of flushes, whether automatic or user activated. The amount of water used for cleansing and handwashing depends on user behavior and is measured by difference within mass balance.

In open loop, the OHT is the water source for all functions in the e-toilet: cistern flush, floor wash, personal wash, and handwashing (Figure S1A). The OHT is filled by a pump in batches of 70-80 from a municipal water tank (MuWT). The volume of water in OHT is obtained by a flowmeter connected between the municipal water tank (MuWT) and the Overhead Tank (OHT). Flowmeter data is manually recorded on a daily basis. In the middle of the open loop, plumbing modifications done and results in the change in volume of cistern flush, floor wash in Table S1.

In closed loop, disinfected treated water is stored in the Treated Water Tank (TWT) **(Figure S2B).** Treated water is recycled for cistern flushing and floor washing. The handwash & personal wash continue to receive water from the OHT. If the number of ECR cycles performed exceeds the capacity of the TWT tank, the excess treated water is disposed of to sewer.

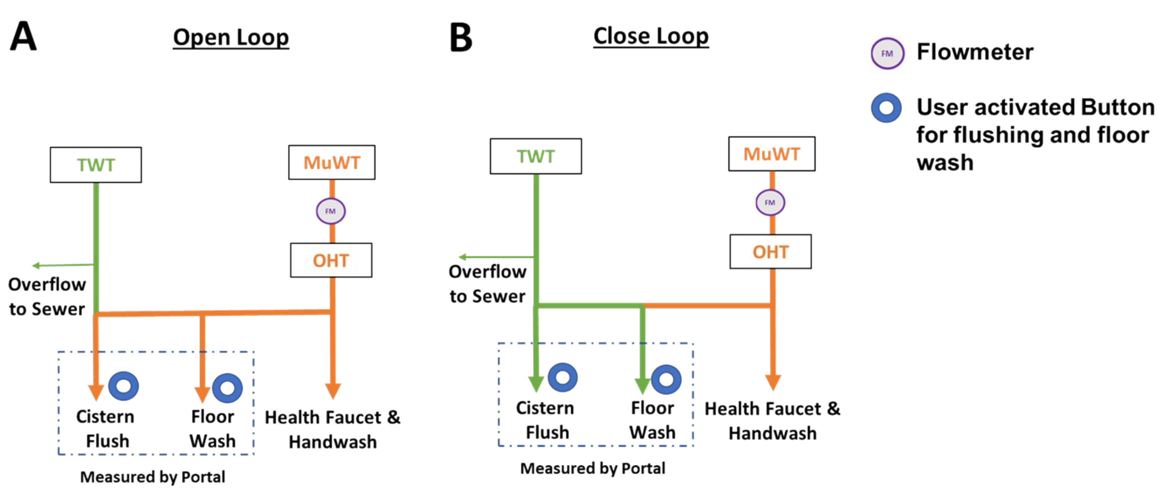

Figure S2. A. Schematic layout of open Loop, **B.** Schematic layout of Closed Loop. Overhead Tank (OHT); municipal water tank (MuWT); the Treated Water Tank (TWT).

Calibrations. The effective volume of treated water pumped out of the ECR after a cycle was measured to be 44L (tank capacity is 50L). The number of ECR cycles is electronically recorded.

The volumes of e-toilet cistern and floor wash were calibrated by adding a known volume of water in an empty OHT using an external pump and activating a specific water use switch multiple times to obtain averages and standard deviations. Results are Table S2.1. A change in plumbing resulted in a modification of the flush volume from P1 values to P2 values. Results are Table S2.1.

Table S2.1. Calibration of Flush and Floor Wash Volume amount. P1: plumbing 1, P2. Plumbing configuration 2.

Loop Status	Pre-Wash Volume (L)	Automatic Flush Volume (L)	Manual Flush Volume (L)	Floor Wash (L)
Open (P1)	0.8 ±0.03	0.8 ±0.03	3.1 ±0.2	4.6 ± 0.8
Open (P2)	0.75 ± 0	0.75 ± 0	2.1 ± 0.1	2.5 ± 0.03
Close	0.8 ± 0.1	0.8 ± 0.1	2 ± 0.1	2.7 ± 0.1

Equations The data collected on the portal website for each toilet visit consists of a time stamp and the event count for each of the following: floor wash, flush (either automatic or user activated), and prewash which were all pre-determined volumes listed in Table S2.1. Thus Portal log volume is the water use for each toilet visit obtained from the sum of all recorded types of flushes. The handwash and personal wash equations used for the water mass balance are as follows:

Open Loop

Handwash & personal wash = MUWT watermeter – portal log total vol (1)

Closed loop

Recycled volume=portal log total (2)

Handwash & personal wash water= MUWT watermeter difference (3)

*Overflow to sewer – (Number of ECr cycles *44L)- portal log total* (4)

Results. Calculated water use by water type and use type are summarized in table S2.2 . Initially, the average water use was 6.1 ± 1.2 L/user; after reducing the volume assigned to floor wash and manual flush, this amount decreased to 5.3 ± 0.7 L/user and remained similar in closed loop. An important learning from this analysis is the measurement of the average amoung of water used for personal wash, which was found to be between 1 and 1.5 L/use, approximately 20% of the overall water volume used.

In closed loop, the total amount of reclaimed treated water used for toilet flushing was 8404 L. The amount of treated water produced during the closed loop period was 15268 L, thus a volume of (15268-8404) L= 6864 L of treated water was sent to overflow.

By dividing this quantity by the capacity 2200 of the ABR, we estimated the 381% water reuse. After completion of the study and before shutting the system continue to operated up to 412% recycled treated water

Table S2.2: Water Consumption Values as per Total Number of Users, Days Operated, Volume Recycled

Loop Status	Days	Users	Treated water reused (L)	Total Water per toilet visit (L/user)	Freshwater (L/user)	Flush and floor wash (L/user)	Handwash and Personal wash (L/user)
Open (P1)	108	1751	0	6.1 ± 1.2	6.1 ± 1.2	5.6 ± 0.9	1.1 ± 0.8
Open (P2)	57	815	0	5.3 ± 0.7	5.3 ± 0.7	3.9 ± 0.4	1.5 ± 0.5
Close	190	2189	8404	5.1 ± 1.0	1.0 ± 0.5	4.1 ± 0.8	1.0 ± 0.5

Supplementary 3: Chlorine Evolution Rate and effect of NaCl addition

Chlorine Evolution Rate (CER) is the rate of FCl generation, measured in a 16 minutes test in the laboratory with electrodes in tanks with deionized water (0 mM Cl), 10 mM and 20 mM salt concentration.

CER performed after 2400 hours highly reduced (20 times) FCl generation at 10mM chloride over new electrodes and a reduced (4 times) FCl generation at 20mM. A chloride concentration of 40mM on aged electrode approximates the CER of new electrodes at 20mM

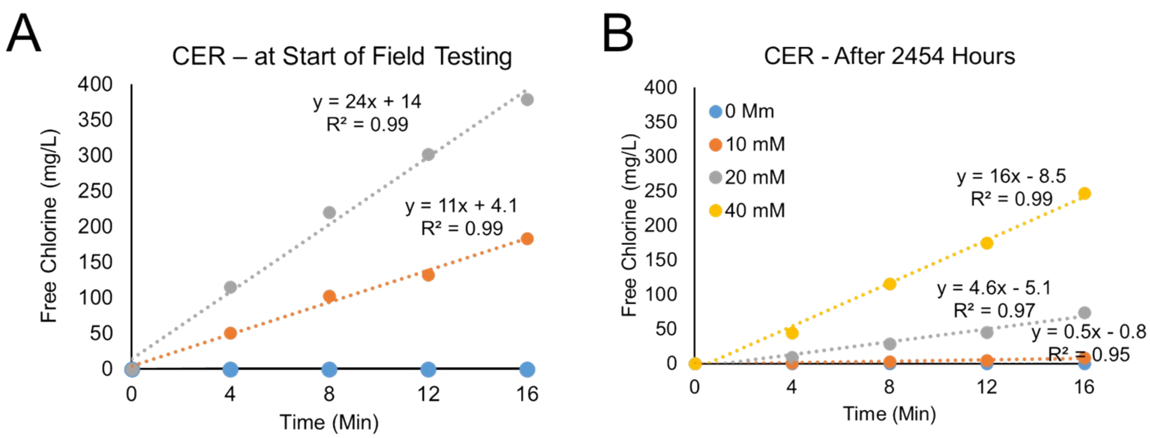

Figure S3.1 A. Chlorine Evaluation Rate at the start of the field testing (0 Hours), **B.** CER after 2400-hours of operation. Curves at 0,10 and 20mM salt concentration and for B 40 mM.

Figure S3.2 shows data before and after NaCl addition to ABR 4 wastewater.

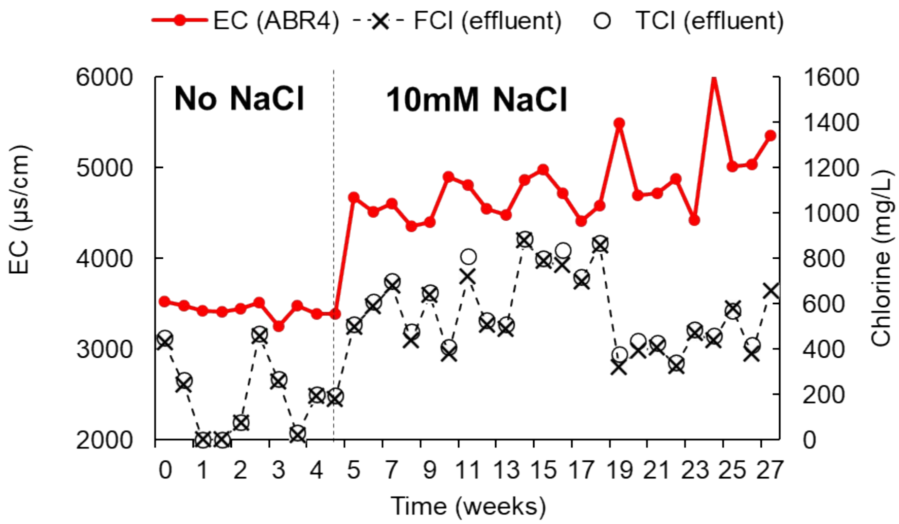

Figure S3.2 Effect of NaCl addition to chlorine production. Effluent Free and Total Chlorine and corresponding conductiibyt of ABR 4 measured over time. Dashed line indicates beginning of 10mM NaCl addition

Supplementary 4 Additional physico-chemical parameters

Ammonia

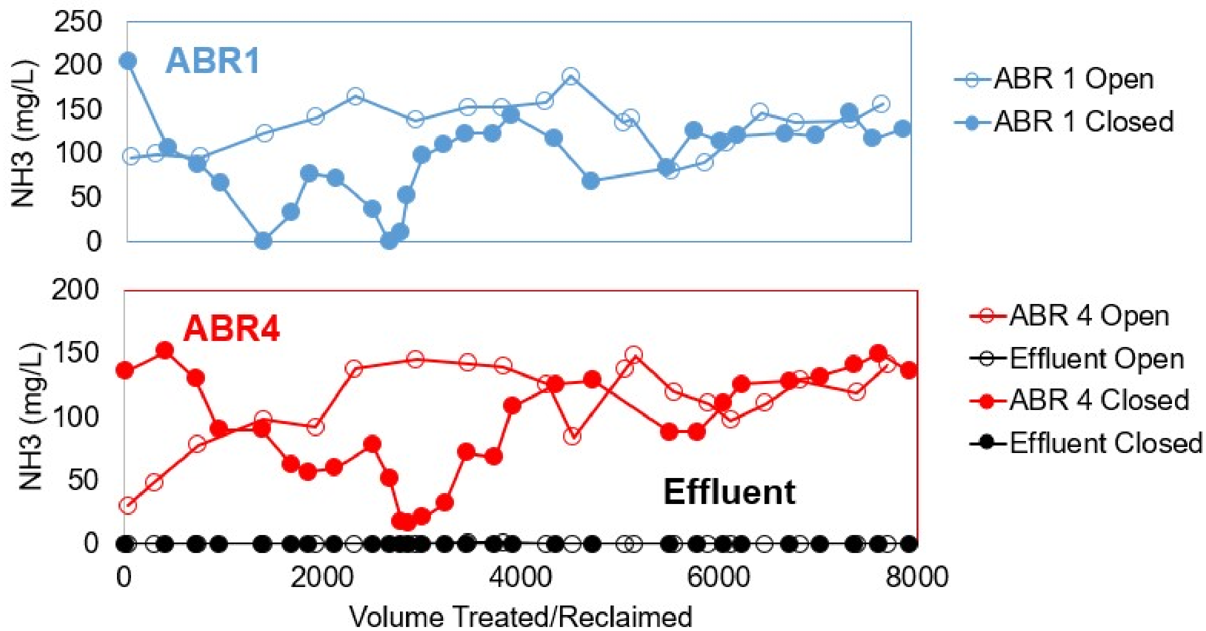

Figure S4.1. Ammonia values over volume treated A. Ammonia performance levels in pre (ABR1), post biological (ABR4) & Electrochemical treatment (Effluent).

pH

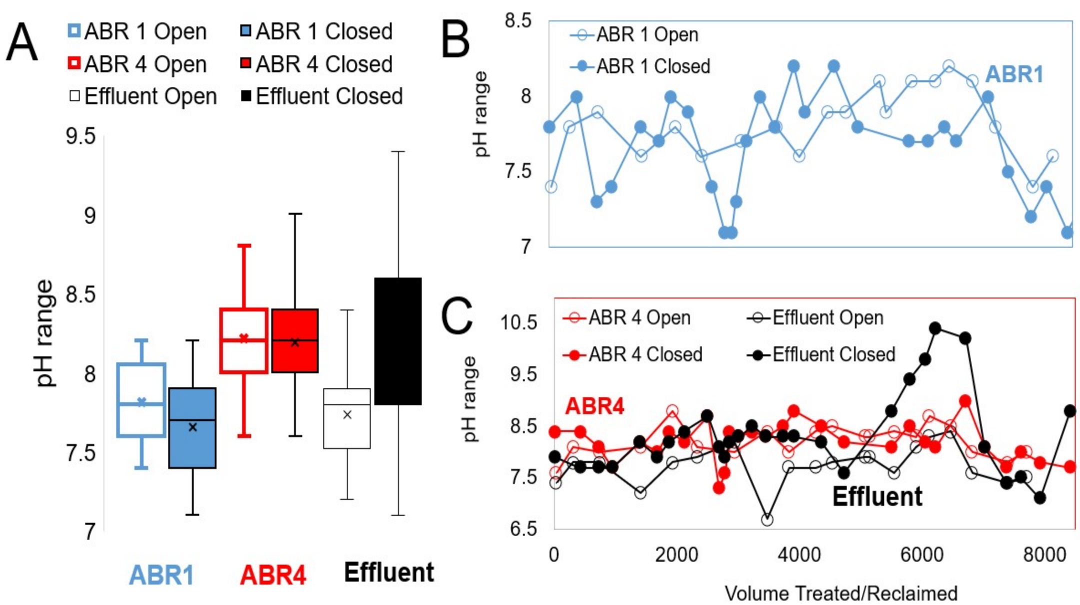

Figure S4.2. A. pH values for sampling point ABR1, ABR4 and Effluent. pH values over volume treated for B. ABR1 and C. ABR4 and effluent

Supplementary 5. Parameters comparison of influent and effluent

Table S5. Physico-chemical and biological parameters comparing Influent (ABR1) to Effluent (ECR out in open loop and TWT in closed loop). Average ± st dev.

Parameters	Open Loop (n = 20)*			Closed Loop (n = 29)*		
	Influent	**Effluent**	**Removal**	**Influent**	**Effluent**	**Removal**
TSS (mg/L)	202 ± 150	8 ± 5	96%	144 ± 99	8 ± 5	94%
COD (mg/L)	662 ± 257	41 ± 19	94%	879 ± 277	118 ± 45	83%
pH	7.8 ± 0.2	7.7 ± 0.4	-	7.7 ± 0.3	8.3 ± 0.8	-
TN (mg/L)	150 ± 33	15 ± 7	90%	113 ± 44	16 ± 9	86%
TP (mg/L)	55 ± 10	22 ± 4	60%	78 ± 20	37 ± 13	53%
NH3 (mg/L)	132 ± 29	BDL	100%	95 ± 47	BDL	100%
Fecal Coliforms (MPN/ml)		<3 (n=7)			<3 (n=9)	

*Unless otherwise specified.

Supplementary 6. Chloride Mass Balance

For the purposes of interpreting the chloroform byproduct generation spike at the end of the closed loop period, a simple model was built for chloride (Cl^-) daily addition and concentration at the different treatment stages for the 205 days of operation in closed loop. The model used data from literature and from measurement about Cl^-, and, as a boundary, the effect of Chloride on electrical conductivity (EC), that was measured regularly.

The findings of this mass balance calculation was that that Cl^- concentration in the influent of the electrochemical reactor was estimated to be 22 mM in open loop condition and twice as much at 49 mM in closed loop condition.

Chloride (Cl^-) sources

Urine: In urine, the chloride concentration in one urination was estimated to be 1 g/user (Udert 2006). The amount of chloride in feces (approximately 0.1 g/user, Rose 2015) was found to be 10% of the urine value and was disregarded.

Tap water: Cl^- in tap water was 9 mM. Tap water in open loop operation was used for handwash, personal wash, and flushing and floor wash (F&FW). In closed-loop operation, borewell water was used only for personal wash activities and recycled water was used for F&FW. The volume of water used from these two sources were obtained from supplementary S2 and from the average number of users.

Salt Addition: manual NaCl addition.

Relationship between EC and Cl^-

We measured the impact of salt addition to EC by adding a known amount to water (Figure S6.1).

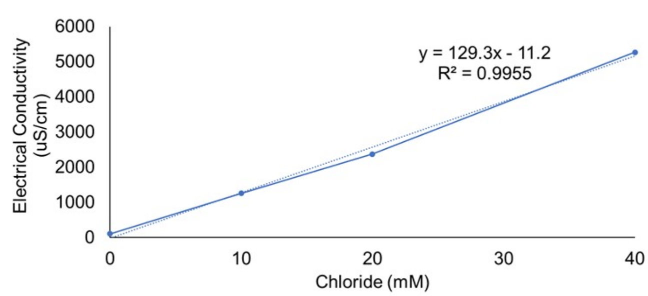

Figure S6.1. Electrical Conductivity (Measured) vs Chloride Concentration (Salt addition)

$$EC\left(\frac{uS}{cm}\right) = (129.3 * chloride\ mM) - 11.2 \tag{1}$$

Estimate of upper limit of chloride consumed in ECR reaction

While the electrodes used in this study require a relatively high Cl concentration (> 20mM) to achieve breakpoint, only a small amount of Cl- was expected to be converted in chlorine.

We estimated an upper limit of chloride conversion to chlorine gas based on EC measurements to be 5.5 mM and assumed it was 4mM for the model.

The change in electrical conductivity (Δ EC) occurring before and after the electrochemical reaction was observed to be in average 1500 uS/cm in open loop and 700 uS/cm in closed loop. The mineral deposit precipitation was more pronounced in open loop, as demonstrated by the high-frequency deposit cleaning in open loop (every 87 ± 32 hours), versus closed loop (197 ± 54 cycles). We deduce from this that the concentration of calcium and other minerals was higher in the open loop than closed loop, where water whose minerals had already precipitated was reused. Using equation 1 and 700 uS/cm, the upper limit of Cl- being converted to gas is 5.5 mM. For the purpose of the remainder of the calculations we used 4mM as the amount of Cl- consumed during electrochlorination .

Chloride Mass Balance in open loop

In open loop a measured average of 16 users per day used 92 L/day of borewell water. Hand washing and health faucet consumption was 16 L/day or 18% of total usage which was assumed to be equally split between ABR 1 and ABR 4.

The calculated mass of chloride in ABR1 is the contribution of chloride from urine and from water.

$$ABR\ 1\left(\frac{g}{day}\right) = \left(\left(\left(urine\left(\frac{g}{user}\right)\right) + \left(F\ \&\ FW\left(\frac{L}{user}\right) x\ Tap\left(\frac{g}{L}\right)\right)\right) x\ users/day\right) \tag{2a}$$

$$ABR\ 1\left(\frac{g}{L}\right) = \frac{ABR\ 1\left(\frac{g}{day}\right)}{Daily\ vol\ into\ ABR} \tag{2b}$$

The amount of Chloride added daily to ABR 4 (volume 700L) is the sum of the amount added to ABR 1 (assuming 92 L displaced volume from ABR 1), handwash water, and salt addition.

$$ABR\ 4\ (g/day) = ABR\ 1\left(\frac{g}{day}\right) + H.wash\left(\frac{g}{day}\right) + salt\left(\frac{g}{day}\right) \tag{3a}$$

$$ABR\ 4\ (g/L) = \left(ABR\ 1\left(\frac{g}{L}\right) x \left(\frac{700 - 92(L)}{700(L)}\right)\right) + 10mM\ salt\left(\frac{g}{L}\right) + \left(\frac{h.wash\left(\frac{L}{user}\right) x\ users}{700(L)}\right) \quad (3b)$$

Open Loop

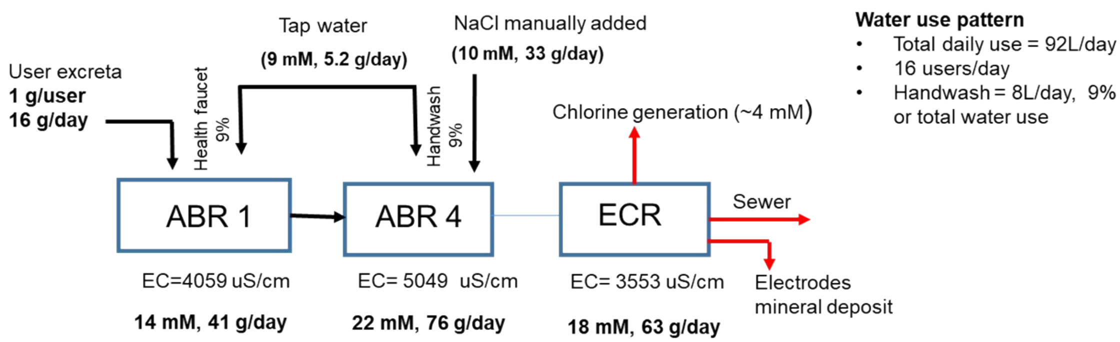

Figure S6.2. Open loop chloride mass balance results in 14 mM in ABR 1, 22 mM in ABR4 and 18 mM in ECR out. All values refer to Cl- unless otherwise indicated.

Effluent chloride is calculated as the difference between the ABR 4 and the estimated chloride consumption rate in the ECR. The mass balance of chloride in open loop is shown in Figure S6.2. About 14 mM chloride in ABR 1 is in agreement with one experimental data point and ABR 4, influent to the ECR was estimated to be 22mM Cl-.

Chloride Mass Balance in closed loop

For the closed loop configuration a model was built for daily addition and concentration for the 205 days of operation in closed loop.

The chloride concentration on the last day of open loop treated water (g/l) was used as the flush water concentration on the first day of closed loop. The mass of daily chloride entering ABR 1 in closed loop was the sum of urine and chloride from the reclaimed water. The ABR 1 Cl- concentration was calculated using the previous day concentration and volume of ABR chamber 1,2,3 (1500 L), equation 4a,b.

$$ABR\ 1\left(\frac{g}{day}\right) = \left(\left(\frac{Urine(L)}{user} * Urine\left(\frac{g}{L}\right)\right) + \left(\frac{F\&FW\ (L)}{user} * F\&FW\left(\frac{g}{L}\right)\right)\right) * \left(\frac{User}{day}\right) \quad (4\ a)$$

$$ABR\ 1\left(\frac{g}{L}\right) = \left(ABR\ 1\ previous\ day\left(\frac{g}{L}\right)\ x\frac{(1500\ (L) - F\&FW\ (}{1500\ (L)}\right. \quad (4\ b)$$

Cl- daily addition to ABR 4 was calculated by summing ABR 1 chloride content, chloride from the salt addition, and tap water from hand wash eq 5a.

$$ABR\ 4\left(\frac{g}{day}\right) = \left(ABR\ 1\left(\frac{g}{day}\right) + Handwash\left(\frac{g}{day}\right) + Salt\ Addition\left(\frac{g}{day}\right)\right) \quad (5a)$$

The Chloride concentration in ABR4 each day was assumed to be the concentration from the previous day modified by the additions of equations normalized by ABR 4 volume.

$$ABR\ 4\left(\frac{g}{L}\right) = \left(\left(ABR\ 1\left(\frac{g}{L}\right) + salt\ \left(\frac{g}{L}\right)\right) x\left(\frac{Vol\ (L)}{700}\right)\right) + \left(h.wash\left(\frac{g}{L}\right)x\left(h.w\right.\right. \quad (5\ b)$$

Using analogous equations to eq (4) and (5) to estimate EC, we obtain results within 10% from experimentally measured EC minimum, average and maximum values, suggesting the model was an adequate representation of the system.

The outcome of this mass balance calculation was that in closed loop the chloride concentration gradually increased from 22 mM to 49mM, which is a 2.5x factor increase. Figure S6.3 represents the values on the last day of closed loop.

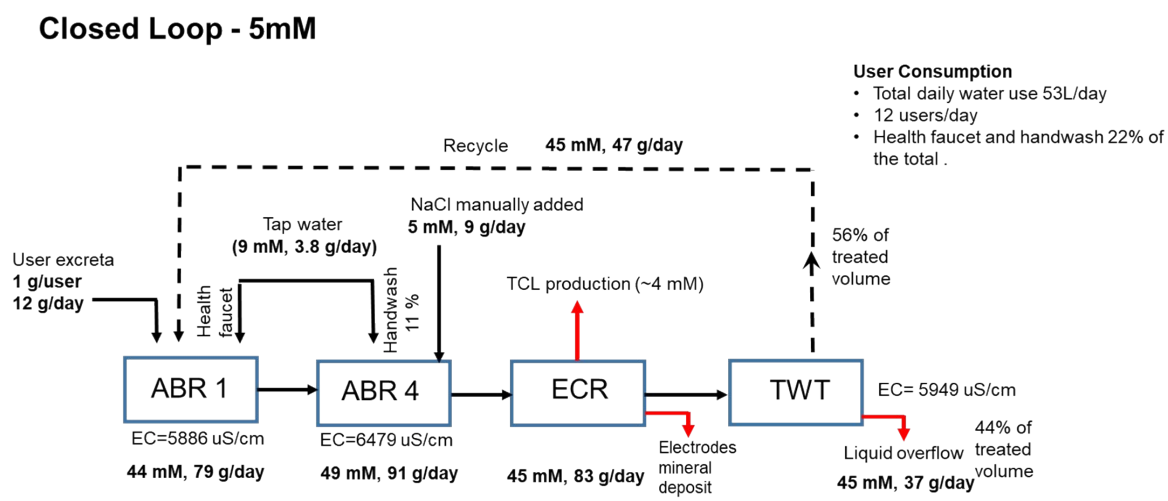

Figure S6.3 Mass balance calculation for Cl- amount and concentration at the end of the closed loop indicating 49 mM in ABR4, the influent of the ECR. All values refer to Cl- unless otherwise indicated. EC values were average of measured value.

References

Rose, C., Parker, A., Jefferson, B. and Cartmell, E. (2015) The characterization of feces and urine: a review of the literature to inform advanced treatment technology. Critical Reviews in Environmental Science and Technology 45(17), 1827-1879.

Udert, K., Larsen, T.A. and Gujer, W. (2006) Fate of major compounds in source-separated urine. Water Science and Technology 54(11-12), 413-420.