1 **Development of a novel off-grid drinking water production system integrating**

2 **electrochemically activated solutions and ultrafiltration membranes.**

3 **Author Names**:

4 Gillian E. Clayton[1]; Robin M.S. Thorn[1]; Darren M. Reynolds[1]

5 **Affiliation**:

6 [1]Centre for Research in Biosciences, Coldharbour Lane, University of the West of England,

7 Bristol, BS16 1QY, United Kingdom

8 **Corresponding Author**:

9 Professor Darren Reynolds. Email: darren.reynolds@uwe.ac.uk

10 **Abstract**

11 Approximately 800 million people live without clean drinking water. Diarrhoea is responsible

12 for between 1.7 and 2 million deaths each year (primarily children) which are the result of

13 poor drinking water quality and sanitation. The main aim of this study was to demonstrate

14 the production of drinking water from a raw water source using an off-grid drinking water

15 production system. The off-grid drinking water production system (DWPS) developed at

16 UWE Bristol, combines an ultra-filtration (UF) system with in situ generation of

17 electrochemically activated solutions (ECAS). ECAS has two functional roles within the

18 system; to manage biofilms within the UF system and as a disinfectant. Integrated in-situ

19 probes (pH, oxidation reduction potential, chlorine, conductivity and dissolved oxygen)

20 coupled with a water quality sensing network (pH, water temperature, conductivity and

21 dissolved oxygen) enabled real time monitoring of; the operational efficiency of the DWPS,

22 and the physicochemical parameters of both the raw water source and the produced drinking

23 water. Spot samples of both raw and treated water were sent for independent chemical and

24 microbial analysis at an accredited laboratory which demonstrated that the DWPS produced

25 biologically safe potable drinking water according to the Drinking Water Inspectorate (DWI)

26 standards. Samples from the raw water source were shown to be consistently unsuitable for

27 human consumption, failing several of the DWI standards for potable water supply, including

28 coliform bacteria. This study demonstrated that the novel off-grid DWPS was capable of

29 producing DWI standard drinking water from a heavily biologically contaminated water

30 source.

31 **Keywords**

32 Off-grid; drinking water production; electrochemically activated solutions; ultrafiltration.

33 **1.0 Introduction**

34 An estimated 800 million people worldwide do not have access to improved drinking water

35 sources [1–3], with 1.2 billion people unable to access reliable electricity sources [4,5].

36 Therefore, there is a need for low energy technological solutions for the provisioning of safe

37 drinking water. By the end of the 21st century the global population is expected to increase to

38 9 - 10 billion [6], this is likely to generate increased stress on water and power (gas and

39 electricity) resources worldwide. Sufficient safe drinking water provisioning for an increasing

40 population will require the development of sustainable, reliable and robust water treatment

41 systems. The consumption of contaminated water, or poor water quality, is the cause of

42 between 1.7 and 2 million deaths each year from diarrhoeal diseases [7–10]. The majority of

43 these deaths are in developing or transitional countries which have inadequate sanitation

44 conditions [11], and do not have established water distribution systems. Developing

45 countries have economies with little industrial development, whilst aiming to improve quality

46 of life through increasing food and water security [12]. Transitional countries often have

47 emerging economies with a prominent secondary manufacturing industry; however, there is

48 still considerable rural and peri-urban poverty [12]. Developed countries have established

49 centralised water, gas and electricity (power) networks, which supply the majority of a

50 country's population with sufficient water, gas and electricity [4]. Developing and transitional

51 countries do not have the same established water and power networks, resulting in many

52 remote, rural or temporary communities unable to access reliable and safe power and

53 drinking water [4]. In developing or transitional countries, communities which are unable to

54 access improved water sources often live in remote or transitory locations, therefore

55 'centralised' drinking water treatment facilities and distribution systems are not sustainable

56 options from a financial or resource efficient perspective.

57 Research into decentralised, or off-grid, drinking water treatment systems for developing

58 countries has gained momentum due to unfeasible practicalities with centralised provision

59 [10,13–15], and are an important element in the process of reaching the Millennium

60 Development Goals. Some decentralised systems focus on rainwater harvesting [10,16,17],

61 solar based disinfection [18,19], or the physical removal of contaminants within treated water

62 through sand bed filters [20,21] or ultrafiltration (UF) [15,22]. Since the main drinking water

63 risks in developing countries are still associated with microbial contamination, many

64 decentralised systems continue to use established disinfection techniques such as UV [18],

65 chlorination [23,24], or ozonation [14]. Even when disinfection agents (e.g. chlorine) are

66 used, the presence of suspended material and colloids in the water can reduce their efficacy,

67 ultimately enabling bacterial growth after treatment [10]. In addition, these disinfection

68 techniques require the regular purchase, transportation and storage of hazardous chemicals

69 and for developing or transitioning countries, this can prove expensive and logistically

70 challenging. A key advantage of off-grid systems is the modular capability, whereby, the

71 production of drinking water output can be increased to cope with increasing

72 populations/demand.

73 Electrochemically activated solutions (ECAS), are known by several terms, the most

74 common being electrochemically activated water (ECAW), electrolyzed water (EW),

75 electrolyzed oxidising water (EOW) and mixed oxidant (MIOX) solutions. These solutions are

76 generated by passing a weak salt solution (e.g. NaCl), through an electrochemical cell,

77 whereupon a direct current is applied. Electrochemically activated solution generated at the

78   anode, referred to in this paper as ECAS, is acidic in nature and possesses antimicrobial

79   chemical species including hypochlorous acid (HClO) and other transient oxidative functional

80   groups [25–27]. ECAS have a short environmental legacy, reverting back to a saline solution

81   during chemical relaxation [25], and are often referred to as 'green biocides' [28,29]. These

82   solutions have been shown to have a beneficial application within; the fresh produce industry

83   [27,30–34], healthcare settings [25,26,35] and drinking water treatment [24,36,37], due to

84   extremely fast acting kill kinetics e.g. < 10 seconds [38,39].

85   The main aim of this study was to demonstrate the production of drinking water from a raw

86   water source (artificial water body) to Drinking Water Inspectorate (DWI) standards, using a

87   decentralised, off-grid, *drinking water production system* (DWPS). The European Council set

88   guidelines for water quality which is safe for human consumption [40], which is interpreted by

89   each European Union member state. In the United Kingdom the Drinking Water Inspectorate

90   (DWI) interprets and regulates drinking water quality.

91

92   **2.0 Materials and methods**

93   2.1 Off-grid drinking water production system

94   A technical schematic of the off-grid drinking water production system (DWPS) is shown in

95   Figure 1. Raw water, from an artificial water body (an urban drainage holding pond, UWE

96   Bristol, UK [N 51° 29' 56", W 2° 32' 39"]), is pumped to a settle tank within the drinking water

97   production system through an intake submersible filter pump (115 µm) and a reverse

98   flushing filter (100 µm). A peristaltic pump draws water from the settle tank into the UF

99   membrane columns ([0.02 µm] LineGuard UF-100, Pentair). ECAS is generated as per

100   details in Section 2.2, and subsequently stored in the ECAS reservoir tank (100L). ECAS is

101   dosed directly into the DWPS pipework, immediately before (A) and after (B) the UF

102   membrane columns via automated peristaltic dosing pumps. Treated water is then stored in

103   the 400 L treated water tank. To monitor the health of the UF membranes, pressure gauges

104   are installed before and after the UF membrane columns.
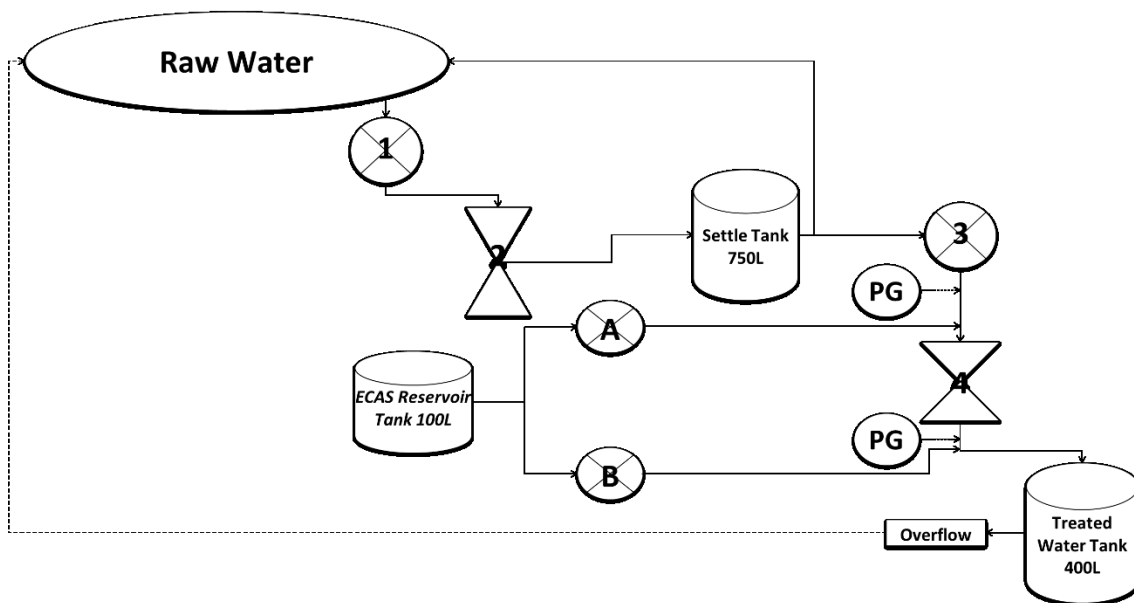
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106

107   **Figure 1**: Technical schematic of the off-grid drinking water production system. Direction of arrows
108   refer to water flow direction. (1) Submersible filter pump (115 µm); (2) Reverse flushing filter (100 µm);
109   (3) Peristaltic pump; (4) UF membrane columns (0.02 µm); ECAS reservoir tank 100L for ECAS
110   generated outside of the DWPS; (A) & (B) ECAS peristaltic dosing pumps for delivering ECAS into the
111   bulk treated water stream; (PG) Pressure gauges.

5

112

113   2.2 Electrochemically activated solution (ECAS) generation

114   ECAS was generated using a 60 L ESOL™ generator (Bridge Biotechnology, Fife, Scotland)

115   through the electrolysis of a 1% (w/v) NaCl solution under a direct current (Figure 2).

116   Solutions were generated (anodic solution) to an oxidation reduction potential (ORP) of 1130

117   mV, and subsequently held and stored within a 100 L reservoir tank until required. Peristaltic

118   dosing pumps enabled precise dosing of ECAS directly into the DWPS pipework pre- and

119   post- ultrafiltration (UF) column membranes.
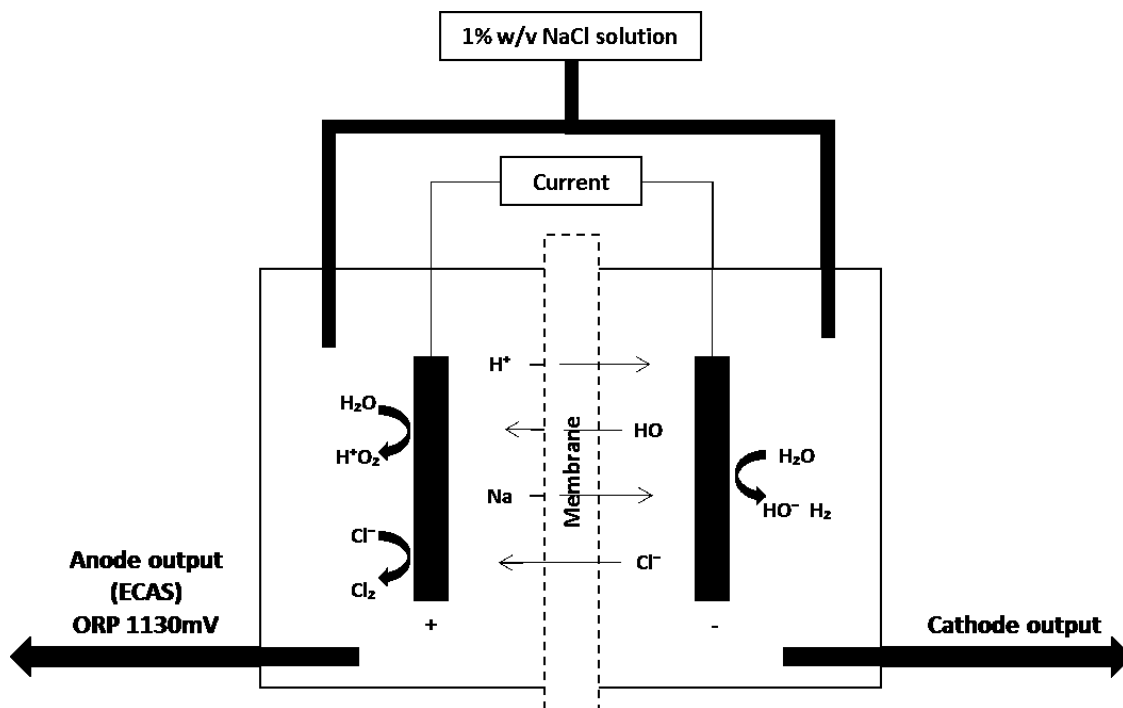
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121   **Figure 2:** Schematic of ECAS generation. A direct current is applied across two electrodes, an anode
122   (+) and cathode (-) separated by a permeable ion exchange membrane, allowing constant perfusion
123   of an electrolyte solution (1% w/v NaCl). The anolyte solution generated (ECAS) has a high oxidising
124   potential, whilst the catholyte solution has a high reducing potential.

125

126   2.3 DWPS Field trials

127   Two field trials were performed. Field trial 1 consisted of dosing 0.5% (v/v) ECAS pre- and

128   post- UF membranes. Resulting in a total of 1% (v/v) ECAS dosed directly into the DWPS

129   pipework. Field trial 2, the control period, had no ECAS dosed pre- and post- UF

130   membranes, resulting in 0% (v/v) ECAS dosage into the DWPS pipework. Both field trials

131   were conducted over 16 operational days. The total time between the end of one field trial

132   and the start of next was 18 days. This downtime between trials allowed for UF membranes

133   to be thoroughly cleaned using alkaline and acid washes using sodium hypochlorite,

134   hydrochloric acid and sodium hypochlorite.

135

136   <u>2.4 Water sampling and analysis</u>

137   Six water samples (both raw water and treated water) were collected and sent for analysis

138   during each field trial. Water samples were collected from the raw water source, and the

139   treated water outlet within the DWPS, before being immediately transported to an

140   independent ISO 17025 accredited laboratory for standard suite analysis. See Table 1 for a

141   full list of parameters tested within the standard suite analysis.

142   To determine the significant difference between raw water and treated water samples

143   throughout field trial 1 and field trial 2, a *t-test* was performed for each parameter listed in

144   Table 1. A *P* value of <0.05 was considered significant. Graph construction and statistical

145   analysis was performed using GraphPad Prism version 5.00 for Windows (GraphPad

146   Software, San Diego, CA), and Microsoft Excel 2013 for Windows (Microsoft Corporation,

147   Redmond, WA).

148   Real-time monitoring of treated water quality (conductivity, oxidation reduction potential

149   [ORP], pH, dissolved oxygen and chlorine), as well as pre- and post- membrane pressures,

150   was performed using a WebMaster data logging system (Walchem, Holliston, MA, USA).

151   UF membrane health was determined by calculating the pressure differential across the UF

152   membrane column module (Equation 1 and Equation 2), and converting this to membrane

153   permeability, the industry standard for membrane health (Equation 3).

154   **Equation 1**: Filtration flux.

$$\text{Filtration flux } (L^{-1}m^{-1}h^{-1}) = \frac{\text{Feedflow } [m^3 h^{-1}] \times 1000}{A \times B \, [m^2]}$$

155   Whereby; UF feedflow is measured on the module, A = Number of membrane housings, and
156   B = Membrane area per membrane housing [m^2]

157

158   **Equation 2**: Transmembrane pressure filtration.

$$\text{Transmembrane Pressure (TMP) filtration } [bar] = PT_{feed} - PT_{permeate}$$

159   **Equation 3**: Permeability UF module.

$$\text{Permeability UF module } [L^{-1}m^{-1}h^{-1}] = \frac{\text{Filtration flux } (L^{-1}m^{-1}h^{-1})}{\text{Transmembrane Pressure (TMP) filtration } [bar]}$$

160

3.0 Results and Discussion

3.1 Field trial 1: 1% (v/v) total ECAS Dosing

Field trial 1, dosing 0.5% ECAS pre- and post- UF membranes, ran for 16 operational days. Table 1 shows the biological, basic water parameters, chemical and metal analysis results for the 6 water samples taken during DWPS operation. Over the entire sampling period all raw water samples analysed prior to treatment failed to meet DWI standards, and were deemed unsafe for human consumption (Table 1). All tested parameters for the DWPS treated water samples were within the specified DWI limits. For example, Table 1 and Figure 3 demonstrate the achieved biological quality of drinking water produced using 1% (v/v) total ECAS as a disinfectant.

Water that was treated by the DWPS was shown to contain zero (0 cfu 100 mL^{-1}) levels of coliforms, *Escherichia coli*, Enterococci and *Clostridium perfringens*. The complete log reduction of bacteria within heterotrophic plates counts at 37°C for 48 hours was achieved for every treated water sample, except operational day 5 ([2 cfu mL^{-1}] Figure 3). However, all treated water samples contained significantly lower heterotrophic bacteria at 37°C than in raw water samples (Table 1), and there is no DWI maximum limit for heterotrophic plate counts (37°C) [41]. Therefore treated water within field trial 1 was deemed fit for human consumption.

The multi-step filtration within the DWPS (Figure 1) resulted in a significant reduction in turbidity between raw water samples and treated water samples, whereby treated water turbidity was within the DWI maximum limit of 4 FTU (Table 1).

The observed increase in the chloride concentration of treated water samples is due to dosing an electrolysed saline solution (ECAS) directly into the water treatment system. However, chloride concentrations for raw and treated water samples were consistently below the DWI limit of 250 mg L^{-1} (Table 1). Figure 4 shows the real-time free chlorine concentration data of the treated water (using the in-line probes), whereby a reading was

187 automatically taken every minute. The frequent chlorine spikes are a result of UF

188 membranes back-flushing, which occur every 30 minutes, resulting in ECAS being dosed

189 into the DWPS pipework in the absence of bulk water flow. Despite this, free chlorine

190 concentrations within the treated water were significantly below the WHO recommended

191 concentration of 5 mg L^{-1} free chlorine in drinking water.

192 It is evident from table 1, that there were significant reductions in aluminium, iron, lead,

193 manganese and zinc concentrations in the treated water compared to the raw water source.

194 The reduction in these metals is due to the multi-step filtration process within the DWPS. A

195 significant increase of sodium concentration in treated water samples is due to dosing an

196 electrolysed saline solution (ECAS) directly into the water treatment system. All metals levels

197 measured in the treated water were below the DWI limit for safe drinking water.

198 Permeability of the UF membranes initially decreased prior to stabilising, indicating no

199 significant blocking or biofouling of the UF columns during the course of this field trial (Figure

200 5). Biofouling can be a result of biofilm formation [42,43]; however, ECAS has been shown to

201 be effective in inhibiting biofilm formation [25,37,44] The regular spikes in permeability are a

202 result of UF membrane back-flushing every 30 minutes, which artificially impacts on the

203 measured pressure differential across the columns.

204 3.2 Field Trial 2: 0% ECAS Dosing (Control Period)

205 Table 1 shows the biological, basic water parameters, chemical and metal analysis results

206 for the 6 water samples taken during DWPS operation in the absence of ECAS dosing. All

207 water samples taken and analysed from the raw water source failed to meet DWI

208 specifications and were deemed unsafe for human consumption (Table 1).

209 During Field Trial 2 (in the absence of ECAS dosing), the DWPS did not produce drinking

210 water to DWI standards. Coliform bacterial counts exceeded the maximum allowance of 0

211 cfu 100 mL^{-1}, producing a mean result of 76.67 cfu mL^{-1}. Non-lactose fermenters within

212 treated water samples were significantly higher compared to raw water samples. However,

213   there were no recovered presumptive *E. coli*, *E. coli*, *Clostridium perfringens* and enterococci

214   from treated water samples (Table 1).

215   Table 1 demonstrates that multi step filtration within the DWPS resulted in a significant

216   reduction in turbidity between the raw water and the treated water, bringing the treated water

217   sample to within DWI limits. No significant difference was observed between the raw water

218   and treated for any of the measured chemical parameters (ammonium, chloride, nitrate,

219   nitrite, orthophosphate, silica and sulphate), and were within the DWI limits. The free

220   chlorine concentration of treated water over the 16 operational days was below the limit of

221   reliable detection for the in-line sensor (< 0.12 mg L^{-1}), which is expected since no ECAS

222   was dosed into the DWPS.

223   Metal analysis of the raw and treated water samples resulted in significant reduction of

224   aluminium, iron, lead and zinc (Table 1). Since this was observed in both field trials

225   (presence and absence of ECAS dosing), it can be concluded that reduction is due to the

226   multi-step filtration process alone within the DWPS.

227

228 **Table 1**: Analytical results of the raw water samples and treated water samples. Field trial 1: 1% total ECAS dosing UF membrane. Field trial 2: Control, 0%
229 ECAS UF membrane. Results shown are the calculated mean from the independent ISO 17025 accredited laboratory reports (n=6 ±SD). Significant
230 difference (Sig. diff) calculated through an unpaired, two tailed t-test, with a confidence interval of 95% (*** = $p<0.001$; ** = $p<0.01$; * = $p<0.05$; ns = not
231 significant). **Bold figures** = Above DWI limit value.

Water type		FIELD TRIAL 1 (1% total ECAS dosing)					FIELD TRIAL 2 (Control; 0% ECAS dosing)					
		Raw water		Treated water			Raw Water		Treated water			
	UNIT	Mean	SD	Mean	SD	Sig. diff	Mean	SD	Mean	SD	Sig diff.	*DWI Limit*
BIOLOGICAL												
Plate count (2 day @ 37°c)	/ml	538.83	753.19	0.33	0.82	***	672.60	778.93	457.33	518.80	ns	
Plate count (3 day @ 22°c)	/ml	2685.33	770.77	2690.67	757.71	ns	12769.40	11209.42	2330.00	596.80	ns	
Non-lactose fermenters	/100ml	33.33	51.64	1.17	2.86	***	0.00	0.00	13.67	33.48	***	
Presumptive coliform bacteria	/100ml	49.17	43.19	0.00	0.00	***	1913.33	3977.37	86.50	66.51	ns	
Coliform bacteria	/100ml	**12.00**	8.29	0.00	0.00	***	**1913.33**	3977.37	**76.67**	73.55	ns	*0*
Presumptive *E.coli*	/100ml	1.50	0.71	0.00	0.00	***	573.33	832.99	0.00	0.00	***	
Escherichia coli	/100ml	1.50	0.71	0.00	0.00	***	573.33	832.99	0.00	0.00	***	
Clostridium perfringens	/100ml	**95.83**	11.70	0.00	0.00	***	**115.33**	82.65	0.00	0.00	***	*0*
Enterococci	/100ml	**52.67**	42.04	0.00	0.00	***	**88.67**	88.59	0.00	0.00	***	*0*
BASIC WATER PARAMETERS												
Alkalinity		139.00	2.65	131.50	7.78	ns	155.00	31.11	154.00	31.11	ns	
Colour (spectrophotometer)	mg L^{-1} Pt/Co	5.60	0.55	4.00	1.79	ns	8.33	1.37	7.67	1.53	ns	
Colour estimated	Deg Hazen	5.00	0.00	5.00	0.00	ns	5.00	0.00	5.00	0.00	ns	
Conductivity	µS cm^{-1} @ 20°C	708.00	69.80	764.17	151.18	ns	610.33	53.71	613.17	52.53	ns	*2500*
pH		8.88	0.18	8.70	0.37	ns	8.33	0.66	8.22	0.69	ns	*6.5 - 10*
Total hardness	Mg Ca L^{-1}	118.67	13.31	114.93	16.75	ns	109.00	11.33	102.93	8.23	ns	
Turbidity	FTU	15.60		0.34	0.27	***	27.33	6.86	0.19	0.13	***	*4*
CHEMICAL ANALYSIS												
Ammonium	mg L^{-1}	0.05	0.04	0.03	0.01	ns	0.27	0.29	0.21	0.16	ns	*0.5*
Chloride	mg L^{-1}	96.50	7.66	137.50	5.54	***	63.17	3.54	62.17	3.54	ns	*250*
Nitrate	mg L^{-1}	3.50	0.46	3.77	0.42	ns	1.02	0.55	1.08	0.71	ns	*50*
Nitrite	mg L^{-1}	0.05	0.01	0.04	0.01	ns	0.06	33.68	0.38	33.21	ns	*0.5*

Water type	UNIT	FIELD TRIAL 1 (1% total ECAS dosing)					FIELD TRIAL 2 (Control; 0% ECAS dosing)					
		Raw water		Treated water			Raw Water		Treated water			
		Mean	SD	Mean	SD	Sig. diff	Mean	SD	Mean	SD	Sig diff.	DWI Limit
Orthophosphate	mg L^{-1}	0.10	0.02	0.12	0.02	ns	0.09	0.08	0.12	0.08	ns	
Silica	mg L^{-1}	0.40	0.20	0.45	0.35	ns	0.50	0.74	0.41	0.58	ns	
Sulphate	mg L^{-1}	158.00	40.31	156.83	36.86	ns	126.00	13.53	129.00	13.00	ns	250
METAL ANALYSIS												
Aluminium	µg L^{-1}	**256.67**	183.16	16.67	5.16	**	**463.33**	124.85	23.33	5.77	***	200
Cadmium	µg L^{-1}	0.12	0.04	0.10	0.00	ns	0.10	0.00	0.10	0.00	ns	5
Calcium	mg L^{-1}	103.45	11.07	100.28	14.07	ns	95.50	9.78	92.40	6.22	ns	
Copper	mg L^{-1}	0.01	0.00	0.01	0.00	ns	0.01	0.00	0.01	0.01	ns	
Iron	µg L^{-1}	**316.67**	180.85	10.00	0.00	***	**548.33**	160.18	10.00	0.00	***	200
Lead	µg L^{-1}	5.38	2.43	0.62	0.26	***	8.57	2.38	0.37	0.20	***	25
Magnesium	mg L^{-1}	9.28	1.36	8.95	1.67	ns	8.22	0.91	7.50	0.66	ns	
Manganese	µg L^{-1}	21.00	3.85	4.33	1.97	***	62.67	32.96	25.40	23.89	ns	50
Nickel	µg L^{-1}	2.00	0.00	2.00	0.00	ns	1.68	0.78	1.70	0.73	ns	
Potassium	mg L^{-1}	3.90	0.49	3.65	0.57	ns	3.87	0.38	3.58	0.34	ns	
Sodium	mg L^{-1}	53.17	4.02	75.83	3.66	***	37.50	1.87	36.83	1.33	ns	
Zinc	µg L^{-1}	35.00	13.78	11.67	4.08	**	36.00	15.17	18.00	8.37	*	

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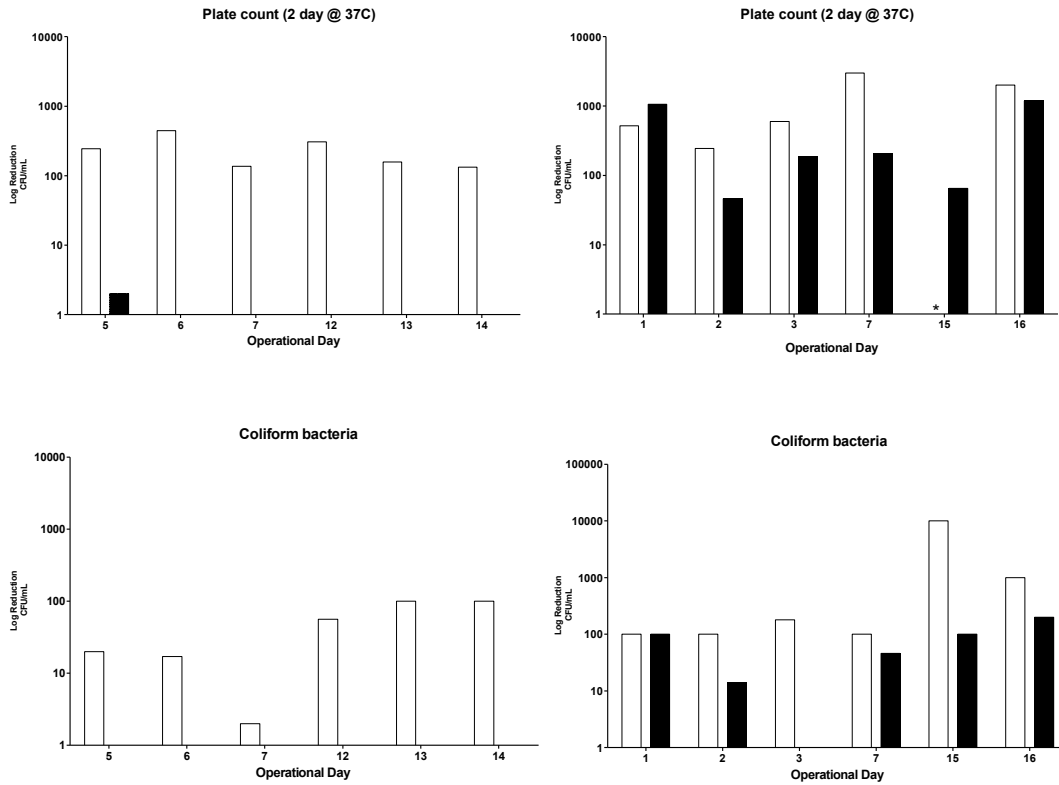
Figure 3: Heterotrophic plate count and coliform bacteriological results for water samples taken during Field Trial 1 (1% total ECAS dosing) and Field Trial 2 (control; no dosing). White bars represent raw water samples. Black bars represent treated water samples. Data taken from independent ISO 17025 accredited laboratory reports (n=1 per sampling day).
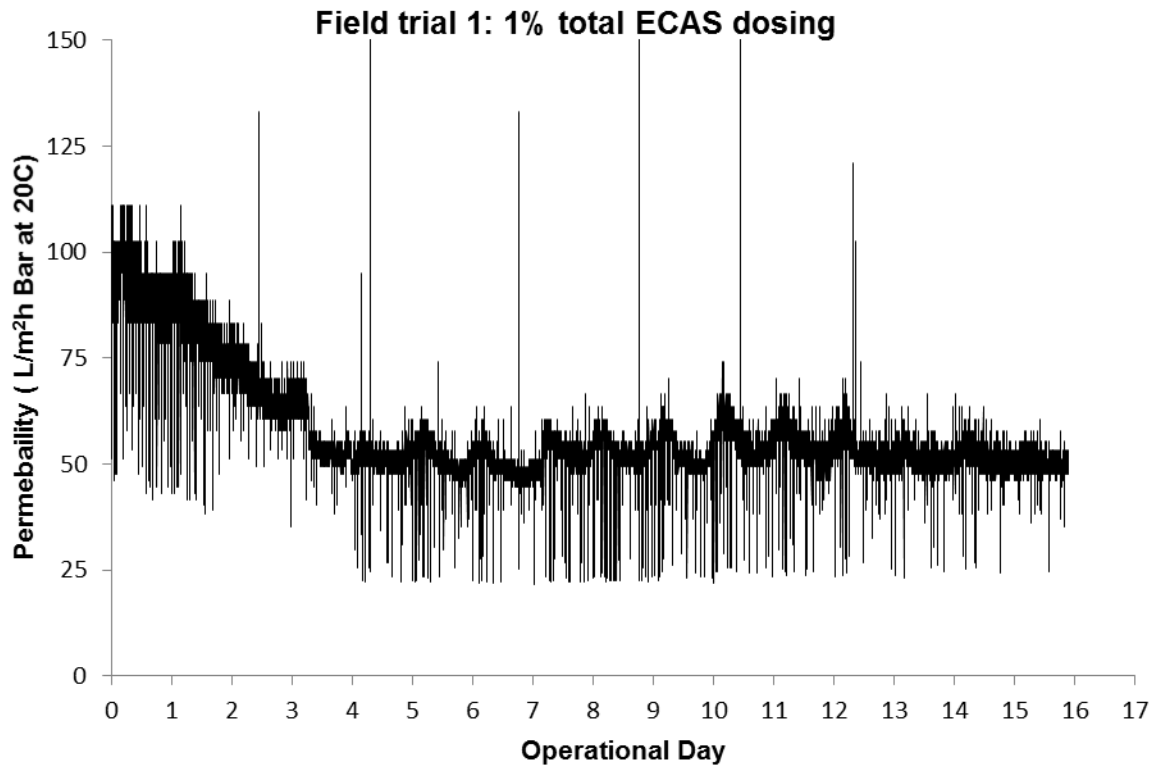
Field trial 1: 1% total ECAS dosing
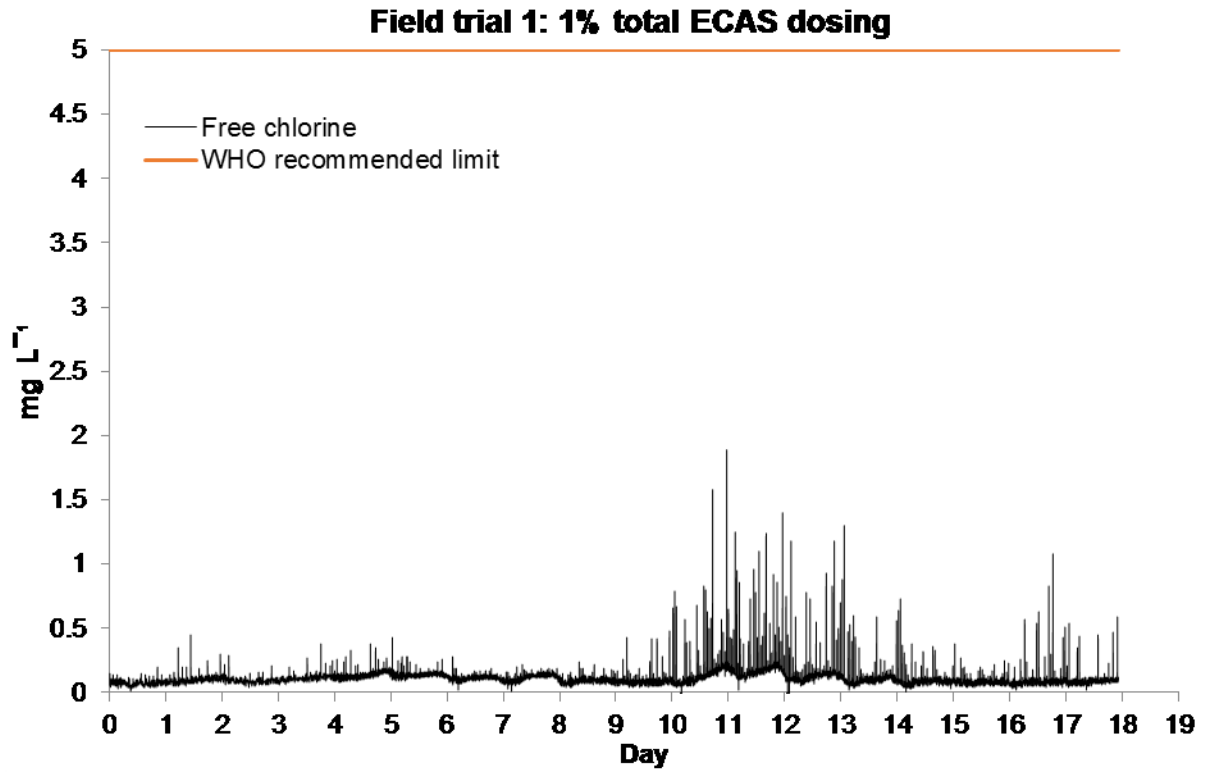
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241 **Figure 4**: Free chlorine concentration (mg L^{-1}) of treated water samples (as recorded by the in-line
242 DWPS probe) for Field Trial 1 (1% total ECAS dosing).

243

244

Field trial 1: 1% total ECAS dosing

245

246   **Figure 5:** UF membrane column permeability within the drinking water production system during Field
247   trial 1 (1% total ECAS dosing).

248

4.0 Conclusions

Two field trials were conducted over two 16 day periods to evaluate the off-grid drinking water production system shown in Figure 1. Field trial 1 performed direct dosing of 1% (v/v) total ECAS into the DWPS pipework, pre- and post- UF membranes. Field trial 2 was a control period, whereby the DWPS was operated in the absence of ECAS (0% ECAS dosing) pre- and post- UF membranes.

All raw water source samples taken throughout the two field trials failed to meet DWI standards and were deemed unsafe for human consumption.

During the control period (Field trial 2) all treated water samples were within DWI limits for basic, chemical and metal parameters. However, the treated water produced was not biologically safe due to the presence of coliform bacteria (Table 1 and Figure 3).

The analysis of all treated water samples resulting from field trial 1, demonstrated that the off-grid DWPS was consistently capable of producing DWI standard drinking water, with all basic, biological, chemical and metal parameters falling within the DWI threshold limits (coliform bacteria, C*lostridium perfingens,* enterococci, conductivity, pH, turbidity, ammonium, chloride, nitrate, nitrite, sulphate, aluminium, cadmium, iron, lead and manganese).

In particular, the microbiological results from field trial 1 treated water samples demonstrated the importance of ECAS dosing in the production of biologically safe drinking water to DWI standards.

The stable permeability of the UF membranes during field trial 1 (whereby 0.5% (v/v) ECAS was dosed pre-UF membranes), indicates that ECAS may help manage biofilm formation on the UF membranes. During Field trial 2 (control; no dosing) greater fluctuations in permeability within the UF membranes was observed, indicative of less stability, and possible biofilm formation (data not shown). This inference of reduced biofilm formation,

274   reducing the possibility of biofouling using 0.5% (v/v) ECAS dosing pre-UF membranes,

275   requires further investigation.

276   Through a systems based hazard analysis the critical control points of the DWPS focus on

277   the in-line monitoring parameters, specifically ORP and free chlorine. Two key critical

278   variables are continuously measured in the WebMaster data logger, chlorine and ORP,

279   ensuring the risks of biological and physicochemical contamination in the DWPS final treated

280   water are minimised. The guideline value for chlorine is 5 mg L^{-1}, a European requirement

281   for ensuring adequate residual disinfection within distribution systems. In addition, due to the

282   nature of ECAS as a disinfectant; high ORP (+1130 mV), low free chlorine concentration,

283   compared to conventional chlorination, and very fast acting kill kinetics (< 10 seconds), ORP

284   is a key parameter to ensure production of biologically safe drinking water. Regular spot

285   sampling of the treated water for biological, basic, chemical and metal analysis is required to

286   ensure DWI compliance. A complete assessment regarding the hazards and critical control

287   points of the DWPS shall be carried out as part of any future work.

288   This study has shown that a novel off-grid drinking water production system can produce

289   DWI standard drinking water from a heavily biologically contaminated water source, when a

290   1% (v/v) total ECAS dosing regimen is implemented. The DWPS was developed with the

291   intention of use in a wide variety of applications and locations, such as developing and

292   transitional countries, many of which lack established centralised water treatment networks.

293   The potential modular and scalable capability of the DWPS could be beneficial in remote,

294   rural or temporary communities, which can have fluctuating populations. The self-contained

295   nature of the DWPS, all filtration and disinfection processes are within the DWPS (except for

296   intake filter pump), could be beneficial for temporary communities such as long-term

297   research expeditions, or during disaster relief efforts. Long-term field trials are now required

298   to obtain data for more representative applications, such as raw water sources from surface

299   and ground waters, which have differing 'contaminants' (e.g. fertilisers, heavy metals, faecal

300   contamination), ensuring the DWPS is capable and versatile in a wide variety of applications.

301   Investigations into the energy requirements for the DWPS are currently being conducted to

302   ensure that the DWPS is robust and reliable for long-term operation.

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