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Non-Potable Water Quality Assessment Results for Water Conservation in the Context of a Medical Facility Case Study

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Abstract: This paper discusses recycled non-potable water (NPW) quality test results from an existing, decentralized, treated air handling unit (AHU) air conditioning (A/C) condensate water (CW) system in a medical facility case study (MFCS) in Abu Dhabi (AD), the capital city of the United Arab Emirates (UAE). The MFCS, a 364-bed hospital that opened in 2015 with 50% landscaping, is targeting 100% non-clinical/non-potable water use for landscape irrigation (LI) from 179,700 m^3/year treated CW, which is a by-product of AHU A/C. For seven months per year, however, a deficit of 14,340 m^3 AHU A/C CW occurs, so costly and non-sustainable, desalinated potable water is required. The proposed change project, using a mixed methodology, develops a sustainable NPW strategy, including a protocol to extract water from recycled, onsite, organic food waste, fire sprinkler pump test water (FSPTW), and reverse osmosis reject water (RORW) to meet the AHU A/C CW shortfall by adapting, enhancing, and monitoring the medical facility's NPW treatment system. The hospital's sustainability strategy implemented by the author could be legislated and mandated by the relevant authority for regional medical facilities, taking the form of a water conservation protocol including the classification and characterization of different types of NPW to understand their impact on LI, human health, and building water systems. The outcome is a novel change in practice to reuse 25,141 m^3/year RORW and 1136 m^3/year FSPTW as makeup water for the A/C CW shortfall in winter. The results identify key considerations to be addressed by the target audience (building owners, landscape contractors, and facility managers) when reusing NPW to protect the environment against soil degradation—a major aspect of decarbonization.

Keywords: water sustainability; wastewater; access to water; water scarcity

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1. Introduction

This paper discusses recycled non-potable water (NPW) quality test results from an existing, decentralized NPW system assessed in a medical facility case study (MFCS) in Abu Dhabi (AD), the capital city of the United Arab Emirates (UAE). The NPW is reused for landscape irrigation (LI) and in water features (WFs) onsite based on a methodology published by Seguela et al. [1] and on a proposed sustainable water conservation (SWC) protocol to further save, recycle, and reuse non-potable water, as developed in studies by Seguela [2] and Seguela et al. [3].

The UAE is a Middle Eastern country with a hot, desert-type climate and the lowest freshwater resource endowment in the world [4]. In 2020, the UAE suffered a water deficit (demand greater than supply), and, with increasing population and per capita water use, demand is projected to increase by 60% by 2045 [5].

The MFCS landscape is as large as the building footprint, representing more than 50% of the site. At the construction stage, the general contractor estimated water irrigation demand to be 375 cubic meters (m^3) per day. The design of the 364-bed hospital included an air handling unit (AHU) air conditioning (A/C) condensate water (CW) treatment system, which is intended to treat condensate from the air-cooling system to a quality suitable for use for LI and WFs. We propose the shortfall in CW availability during the winter months (December–February) be met by non-potable makeup water types, such as reverse osmosis reject water (RORW), food waste effluent, and fire sprinkler pump test water (FSPTW), in addition to AHU A/C CW.

The aim of the research project is to demonstrate that a hospital can be self-sufficient, irrigating its landscape without the need to draw energy-intensive, desalinated potable water from the municipality. The NPW results may influence regulators to amend their soil and water standards to encourage hospitals to collect and reuse non-clinical NPW for irrigation and avoid water wastage, but also to reduce the need for desalinated water treatment, which also has a very high cost (USD 0.50–1.00 per m^3) compared to conventional sources [6].

The author's proposed change project aims to measure the impact of using onsite NPW resources for a hospital and its landscape in AD to alleviate the use of desalinated potable water and so reduce associated energy consumption, GHG emissions, and operation and maintenance cost and practices [2], in addition to assessing NPW's effect on plant growth. This goal is in line with the United Nations (UN) and UAE Sustainability Goals (SGs) 6, 9, 11, and 13, as illustrated in Figure 1 below.

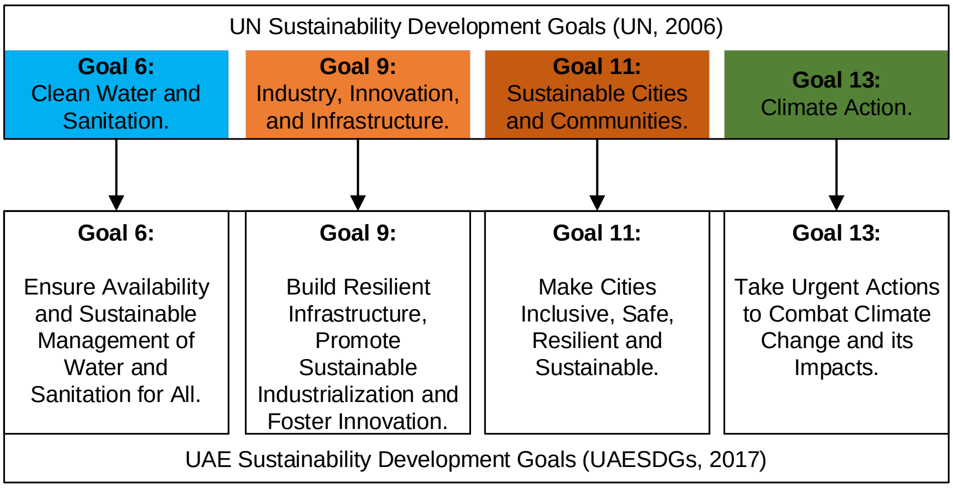

Figure 1. United Nations (UN) and UAE Sustainability Goals (2020). Sources: United Nations [7], UAE [8].

According to the UN [7], billions of people around the world lack access to drinking water, with 70% of all water abstracted from rivers, lakes, and aquifers used for irrigation. Water scarcity affects more than 40% of the global population and is projected to rise. A quarter of healthcare facilities lack basic water services, and over 1.7 billion people currently live in river basins where water use exceeds recharge [7].

In line with UN Goal 6, the UAE developed the "Water Security Strategy 2036" [9], which aims to enhance water security planning and risk management. Among other initiatives, under Goal 9, the UAE launched the "Annual Corporate Social Responsibility National Index" [10] to track UAE-based companies' contributions to corporate social responsibility initiatives. Meeting Goal 11 included the launch of the UAE's "Consensual Holistic Plan" to develop a long-term integrated plan and roadmap for the UAE, which incorporates environmental, urban, economic, and social pillars [11]. Additionally, under Goal 13, different programs have been launched including:

- the "Climate Project" (2018) to raise awareness of climate change and the importance of climate resilience;

- the "Climate Innovation Exchange Forum (CLIX)" to facilitate the sourcing and funding of climate change solutions and technologies;
- the "National Climate Change Plan 2050" to support the transition to a climate-resilient green economy while managing GHG emissions, increasing climate adaptation capabilities, and engaging private sector and other stakeholders to support the mitigation and adaptation efforts of the government; and
- the "National Climate Adaptation Program (2017)" to assess the climate adaptation potential of four key sectors (health, energy, infrastructure, and environment) [12].

The objectives of the research are three-fold:

Objective One: To record water consumption patterns and profiles to allow comparison between different, non-clinical NPW resources at the MFCS.

Objective Two: To test a water conservation framework for water resources and water quality recycling through three interventions and three calculations—namely, CS1 Intervention One (2017 water balance), CS2 Intervention Three (additional non-potable water quality testing), and CS1 Calculation Two (Calc2) (non-potable water quantity estimate)—and analyze the data collected.

Objective Three: To analyze and monitor Objective Two quality of NPW types by using effluent and soil laboratory sampling and testing.

A review of the literature [2] provided evidence, firstly, that the AD soil standard [13] does not address minimum and maximum soil micro- and macronutrient concentration limits for soil maintenance, and, secondly, that the existing water standard does not include salinity water concentration limits, which are essential for conserving soil and can limit water consumption [14]. Seguela [2] provided evidence, based on A/C CW quality test results conducted the MFCS in 2016 and 2017, that CW has the same characteristics as rainwater—because it is extremely low in dissolved salt content measured by sodium absorption ratio (SAR), which can cause soil infiltration rate problems.

It was also found in the literature that NPW recycling is essentially addressed in terms of quantity [15–18], with little in-depth discussion of NPW quality for reuse and, specifically, its effect on soil and plants and corrosive effect on canal linings [19–21].

Hence, the key original and significant contributions to changes in practice from the author's research include a proposed WCS strategy forming the basis for a water protocol specific to arid-climate regions, such as AD, that tests and analyzes various non-clinical NPW resources onsite for LI and WF use and which addresses their physicality, salinity, and sanitary and microbiological characterization for their intended use. Such a protocol can reduce energy-intensive desalinated water consumption, environmental impact, and operational costs and help the UAE to meet its sustainability goals.

2. Methodology

2.1. Research Method

Case Study One (CS1) and Case Study Two (CS2) are graphically represented in Figure 2, which shows the quantitative data collection process [22,23] that links to the research objectives.

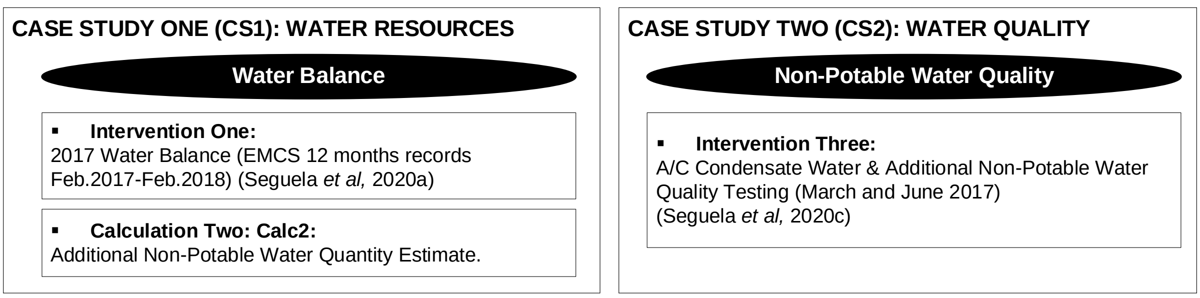

Figure 2. Proposed research strategy summary. Source: Seguela [2].

2.2. CS1 Intervention One: Water Resources

The MFCS included assessment of the hospital's onsite recycled water system compared with its use of municipal, desalinated potable water. A water balance (in 2016 and in 2017) was developed, which included five elements, as illustrated in Figure 3 below (A to E). Elements A, B, C, and E represent the water resources case study (CS1). The water quality case study (CS2) focused on A and E. The data were collected and analyzed via new flow meters 1, 2, 6, and 7 and existing flow meters 3, 5, and 6. The data were monitored daily via the energy monitoring and control system (EMCS).

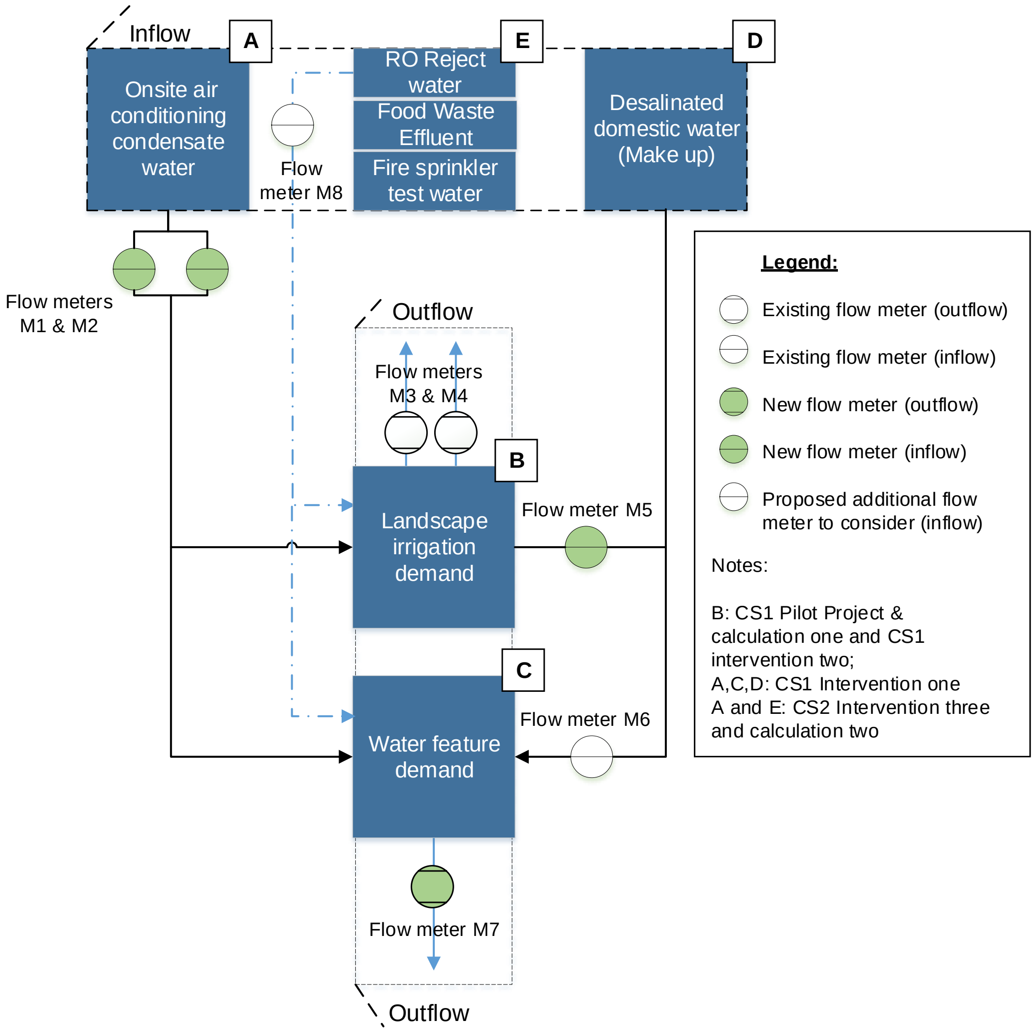

Figure 3. CS1 Intervention One water balance methodology. Sources: Seguela [24], Seguela et al. [25].

2.3. CS2 Intervention Three: Water Quality

Case Study Two used a qualitative data collection process [22] and included Intervention Three [23], as follows, which links to the research objectives in Section 2.1.

Intervention Three (A/C CW and additional NPW quality testing), carried out in March and June 2017, included the testing and analysis of NPW quality from NPW sources, including food waste effluent wastewater, FSPTW, RORW, and the existing AHU A/C CW. It was a study to assess onsite-generated NPW quality in a desert-type climate for outdoor reuse and its effect on the water system, soil, and plant growth.

2.4. CS2 Intervention Three: Non-Potable Water Quality Assessment

In June 2017, water quality tests were performed on four different samples drawn from four different NPW sources at the medical facility: AHU A/C CW, FSPTW, RORW, and food waste effluent. The hospital's recycled water is classified by the Regulation Supervision Bureau (RSB) [26] as suitable for general reuse, which involves frequent and uncontrolled exposure of the public to recycled water.

The substances measured in the water, as per RSB (2010; 2014) requirements and recommended levels [14] for recycled water and for drinking water, are listed below in Table A1 in Appendix A. The water test results were evaluated against these parameters [25].

2.5. CS1 Calculation Two (CS1 Calc2): Additional Non-Potable Water Quantity Estimate

2.5.1. Fire Sprinkler Pump Test Water

As part of the regular inspection, testing and maintenance, the water-based fire protection systems and the fire pumps of the sprinkler system are tested every year at the end of February, in line with the National Fire Protection Association (NFPA) 1911 Standard for Service Tests of Fire Pump Systems on Fire Apparatus [27]. The FSPTW is diverted to a 124 m^3 tank (T41-1 in Figure 4 below) which is then drained to sewage. The consumed potable water in liters per minute (lpm) for test one was estimated using Equation (1) below [28]:

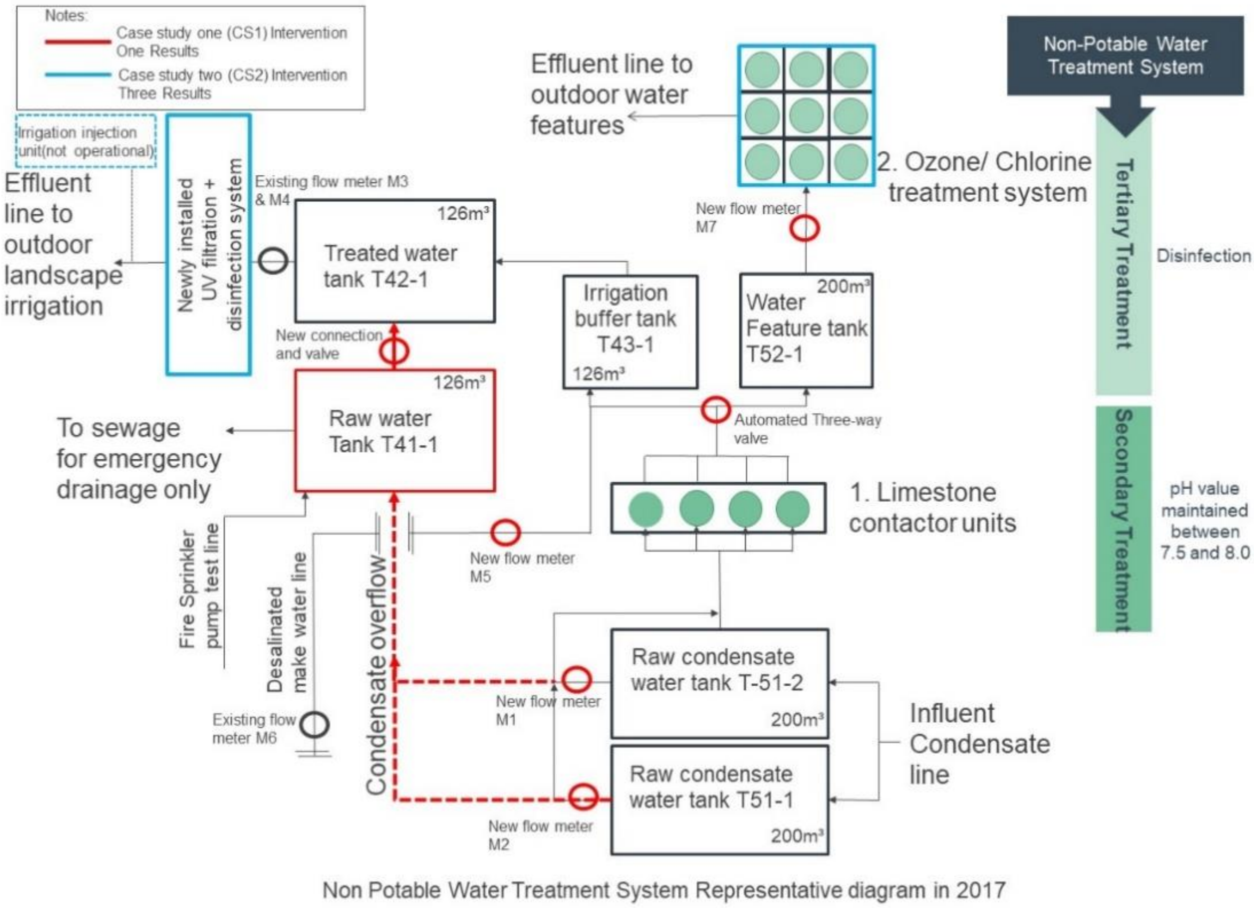

Figure 4. CS1 and CS2 non-potable treatment system enhancement results (diagram), Seguela et al. [25].

Test one water usage (lpm) = [Flow rate (lpm) × pump run duration (minutes)] × 2 (1)

The pump performance tests took 10 min for each pump and, during this time, the flow rate was tested at 100% (test one above) and 150% (test two below) of the system capacity. The estimated potable water used for test two was estimated by using Equation (2) below [28]. The standard pump's flow rate specification was provided by the hydraulic engineer on the project.

Test two water usage (lpm) = [Test one water usage (lpm) × 150] × 2 (2)

The test was thus repeated twice for each test and for the eight pumps. This calculation assumed the length of the test was 10 min for each test, as stated by the MHCS Operations and Maintenance (O&M) team. Thus, the total potable water consumed for the test was calculated using Equation (3) below [28].

Total water consumed (m^3) = Equation One Results + Equation Two Results/1000 (3)

The FSPTW was reported to be of good quality and could be reused for toilets and other sanitary fittings, urban irrigation, cooling towers, car washing, and carpark cleaning [28]. It was also recommended for reuse by the UAE Department of Municipal Affairs and Transport (DMAT) [29] subject to Legionella testing and monitoring. This point is discussed further in Section 4.

2.5.2. Reverse Osmosis Reject Water (RORW)

The MFCS is fitted with two reverse osmosis (RO) treatment systems at level P3 or near the location of the existing conditioning CW treatment system. The configuration of a typical RO unit comprises an inflow feedwater of clear permeate water and an outflow for the rejected water or brine.

The RO membrane consists of two flat sheets of material separated by porous sheets. Feedwater or pre-treated, desalinated raw water enters at one end, and the open side of the membrane envelope is attached to a plastic tube that collects the product—treated water, also called clear permeate water—and rejects the excess feedwater [30]. This reject water is recommended for reuse for LI and/or WFs subject to its total dissolved solids (TDS) level, which must be below 1000 mg/L [31–33].

One RO system (RO 1) is used to sterilize cooling water for the Central Sterile Supply/Services Department (CSSD), which uses RO water in steam generation (Table A1 Appendix A). The other (RO 2) provides sterilized water to the steam boilers which is said to be help reduce chemical use, deionization (removal of all ionized minerals and salts (AWWA, 2010b) [30], and maintenance cost but also improve the quality of the wastewater discharge (Asano et al. 2007).

The RO membrane treats influent water (AD municipality desalinated water) to generate a permeate stream that meets boiler (RO 2) and sterilizer (RO 1) feed criteria such as concentrations of TDS and total suspended solids (TSS), silica, and hardness. After final polishing by ion exchange resins, the clear permeate can be used as boiler and sterilizer feed water. The membrane of a RO has specific characteristics of efficiency of salt rejection, pH operating range, susceptibility to biological attack, and resistance to degradation and hydrolysis (AWWA, 2010b). The feedwater of the RO is pre-treated to prevent premature membrane fouling to avoid excessive calcium carbonate (limestone) or calcium sulphate (gypsum) scales and to prevent fine colloids, iron or other metal oxides, and silica from accumulating [30].

Additionally, as shown in Table 1, the hospital's sterilizers serving the CSSD and the steam boilers are using water through two RO units, which operate for an average of 24 h per day for RO 1 and eight hours per day for RO 2.

Table 1. CS1 Calc2 reverse osmosis operations parameters.

P3 Reverse Osmosis (RO) and RO Water Parameters	Units	Reject Water	
		RO One	RO Two
Run-time operation	hours/day	24	8
RO size	m³/hour	3.3	2.8
Salt rejection rate	%	98	98
Feed water recovery rate	%	70	60

The outflow of RO 1 reject water is 3.3 cubic meters per hour (m^3/h) whereas RO 2 inflow is 2.8 m^3/h. The amount of reject water resulting from the operation of the RO plants ranges from 70% for RO 1 to 60% for RO 2. Additionally, this water is fit for various reuse opportunities subject to feed water quality, such as toilet flushing or LI, because it is low risk and similar to potable water quality [32,33]. Hence, the formula for estimating the outflow quantity of the RORW can be calculated by using Equation (4) below, where H is hours of operation of each RO and V the volumetric flowrate of the unit [33].

$$\text{Volume of RO reject water per day} = H \times V \quad (4)$$

This calculation assumes that the hours of operations remain unchanged.

2.5.3. Food Waste Effluent

The MFCS estimated food waste generation for five years (Figure 5 below). It was estimated in 2016 that 500 to 800 kg of food waste would be generated per day through to 2020 [24]. To minimize impact on the environment and the cost of haulage, in December 2017 the MFCS procured a dehydrator to recycle food waste onsite and to generate a solid by-product with the potential to be transformed into an organic fertilizer. The latter study and analysis are excluded from this research because the onsite produced fertilizer was not tested onsite. In addition to the by-product, the dehydrator generates wastewater in the process. The dehydrator reduces food waste to wastewater at 80–90% of its weight [34]. The food waste effluent quantity was calculated (CS1 Calculation Two (CS1 Calc2)) on this basis.

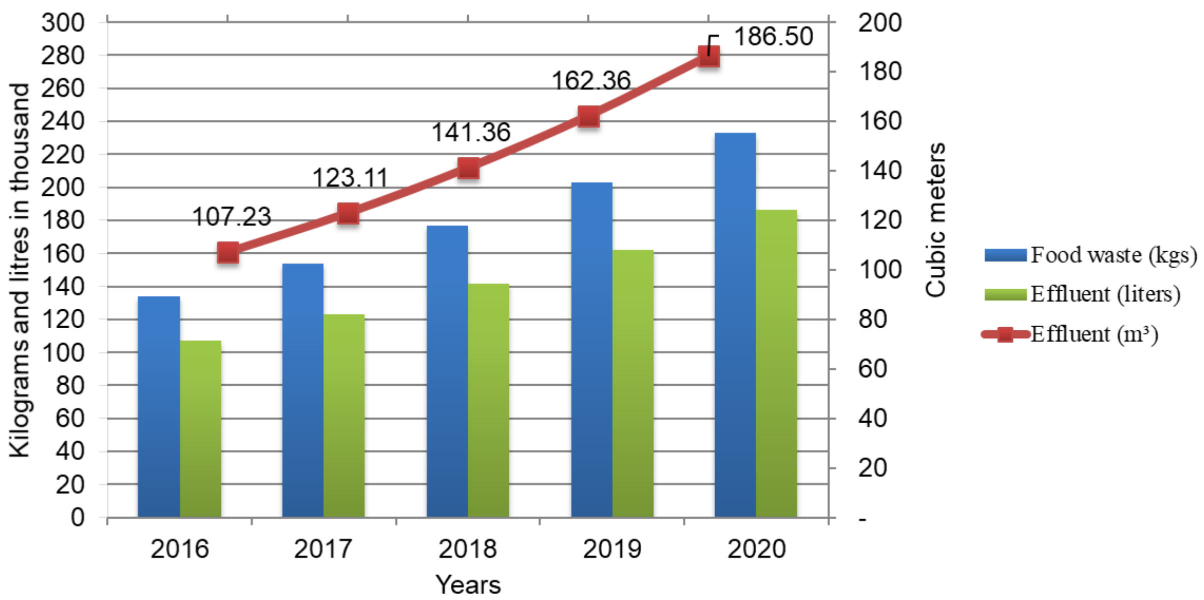

Figure 5. CS1 Calculation two (CS1 Calc2) food waste effluent estimate.

2.5.4. Fire Sprinkler Pump Test Water

As part of the MFCS inspection, testing, and maintenance of water-based fire protection systems, the fire pumps of the sprinkler system are tested every year at the end of February, in line with the National Fire Protection Association (NFPA) 1911 Standard for Service Tests of Fire Pump Systems on Fire Apparatus [27]. The FSPTW is diverted to a 124 m^3 tank (T41-1 in Figure 4), which is then drained to sewage. The consumed potable water in liters per minutes (lpm) for test one can be estimated using Equation (5) below [28]:

$$\text{Test one water usage (lpm)} = [\text{Flow rate (lpm)} \times \text{pump run duration (minutes)}] \times 2 \quad (5)$$

The pump performance test took 10 min for each pump and, during this time, the flow rate was tested at 100% (test one) and 150% (test two) of the system capacity. The estimated potable water used for test two was estimated using Equation (6) below [28]:

$$\text{Test two water usage (lpm)} = [\text{Test one water usage (lpm)} \times 150] \times 2 \quad (6)$$

The test was thus repeated twice for each test and for all eight pumps. This calculation assumed the length of the test was 10 min for each test, as stated by the Operations and Maintenance team. Thus, the total potable water consumed for the test was calculated using Equation (7) below [28].

$$\text{Total water consumed } (m^3) = \text{Equation One Results} + \text{Equation Two Results}/1000 \quad (7)$$

The FSPTW was reported to be of good quality and can be reused for toilets and other sanitary fittings, urban irrigation, cooling towers, car washing, and carpark cleaning [28]. It was also recommended for reuse by DMAT [29] subject to Legionella testing and monitoring. This point is discussed further in Section 4.

The food waste is the food waste effluent input, while the CW input is AHU condensation, and the RORW and FSPTW input is desalinated water, which is relatively constant. This was observed by the author when testing the food waste effluent at various locations, the MFCS included, where the biochemical oxygen demand (BOD), the chemical oxygen demand (COD), and the dissolved oxygen (DO) varied drastically from one location to the next. The food waste effluent, the RORW, and FSPTW laboratory testing is discussed in Section 4.

Figure 3 provides an account of the different non-potable water sources available for reuse at the MFCS, which were tested in accordance with US Environmental Protection Agency (EPA) water treatment recommendations [31] and RSB water quality requirements [26]. The quality of the food waste effluent, FSPTW, and RORW were evaluated against their reuse intent: landscape irrigation (LI) and water features (WFs).

3. Results

3.1. CS1 Calculation Two (CS1 Calc2) Results: Tackling the Water Deficit

3.1.1. Fire Sprinkler Pump Test Water

Based on the calculation method in Section 2.5.1, Table 2 data tabulation provides evidence that the MFCS uses 1136 m^3 of potable desalinated water for the fire sprinkler pump tests every year.

Table 2. CS1 calculation two fire sprinkler pump test water quantity estimate.

Fire Pump Tests	Gallons per Minute (gpm)	Liters per Minute (lpm)	Test One Water Usage in lpm (Equation (1))	Test Two Water Usage in lpm (Equation (2))	Total Water Usage in m^3 (Equation (3))
Pump 1	1250	4732	94,640	141,960	473.20
Pump 2	1250	4732	94,640	141,960	
Pump 3	500	1893	37,860	56,790	189.30

Pump 4	500	1893	37,860	56,790	
Pump 5	750	2839	56,780	85,170	283.90
Pump 6	750	2839	56,780	85,170	
Pump 7	500	1893	37,860	56,790	189.30
Pump 8	500	1893	37,860	56,790	
Total water usage in m^3					1136 (round off)

As part of the 2016 hydraulic review of the MFCS non-potable water system, it was found that there is potential for the FSPTW to be recycled when the water tanks T41-1 and T42-1 are connected with no need for an extra transfer pump (see Figure 4). However, this strategy has not been implemented because the author left the project in September 2017; thus, the water is dumped to sewage.

3.1.2. Reverse Osmosis Reject Water (RORW)

When Equation (4) in Section 2.5.2 is used to quantify the RORW, the results are 13.44 m^3/day for a 60% reject water recovery rate unit (RO 1) and 55.44 m^3/day for a 70% recovery rate unit (RO 2): a total of 25,141 m^3/year.

3.1.3. Food Waste Effluent

As discussed in Section 2.5.3, the dehydrator reduces food waste by 80–90% of its weight [34], which represents the generation of 12.16 m^3 per month average wastewater: 500 kg × 0.8 = 400 L per day. An amount of 400 L is equivalent to 0.4 m^3 per day as 1 m^3 is 1000 L. Thus, 0.4 m^3 × 365 days is 146 m^3/year or 12.16 m^3/month (146 m^3/year ÷ 12 months). If the figure of 90% is used, the food waste effluent represents 16.89 m^3/month for 500 kg of food waste generated in a day. When taking the average between the two estimates, it is 14.52 m^3/month or 0.17% of the air conditioning quantities. Figure 4 below provides the five-year (2016–2020) estimated results.

3.1.4. Overall Additional Non-Potable Water Quantity Results

The quantities for the FSPTW and RORW are the product of a calculation (Sections 2.5.1 and 2.5.2), because flow meters were not installed either at the exit of water tank T41-1 (see fire sprinkler line at Figure 4 or at the exit of the reject water line of the RO 1 and RO 2. In addition, the food waste effluent could only be estimated according to its weight.

Figure 6 below provides an account of the different non-potable water sources available for reuse at the MFCS in a typical year. The AHU A/C CW quantity is included as recorded by the EMCS from February 2017 to January 2018. The results show that a 39 m^3 per day average (14,275 m^3 total based on 366 days) water deficit occurs in a year: 63 m^3 per day in winter (December–February), 77 m^3 per day in spring (March–May), and 37 m^3 per day in autumn (November) 2017.

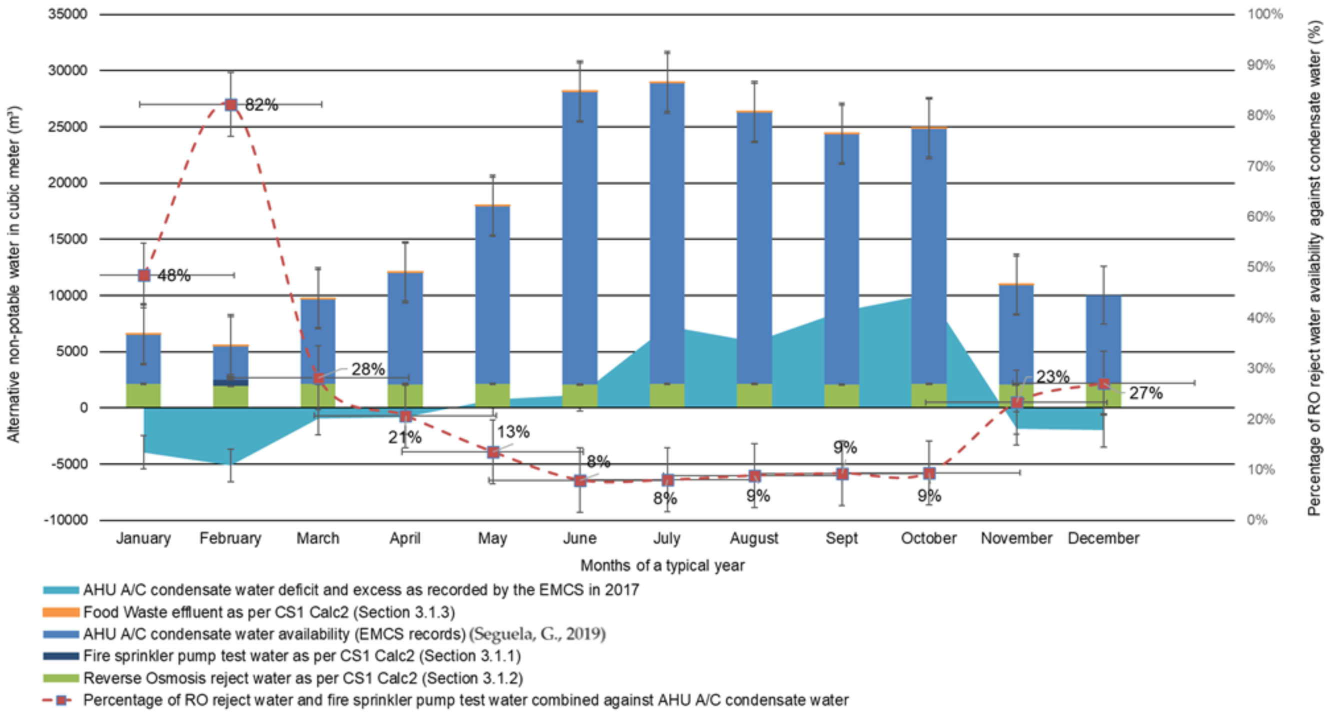

Figure 6. CS1 Calc2 additional non-potable water availability against condensate water supply [2].

Figure 5 indicates that the RORW combined with the FSPTW represents 60% average AHU A/C CW quantity in the winter months (December–February) and a range of 24% to 16% in the spring and autumn months (October–November and March–April), respectively. In the summer months, when non-potable water top-up is not needed, the RORW represents 9.56% average (May–September). This means the RORW and FSPTW have the potential to help fill the CW deficit in winter and spring. This is because, firstly, the RORW and FSPTW are generated the whole year round as they are unrelated to weather; secondly, they are generated regardless of recycling; and, thirdly, their quality is fit for purpose when going through a tertiary treatment such as the CW (see evidence provided in Sections 3.1.2 and 3.1.3 above).

Considering the evidence provided above regarding the food waste effluent quality and the small quantities generated, this water type was excluded from the potential, additional non-potable water sources.

3.2. CS2 Intervention Three Results

This section presents the results of the non-potable water tests, as undertaken by an independent, certified Emirates Authority for Standardization and Methodology laboratory. Non-potable water sources were evaluated against the maximum allowable concentration or characteristics of restricted substances, as specified in Schedules A1 and A2 of the Recycled Water and Biosolids Regulations 2010 [26], in addition to concentration limits (Table A1).

3.2.1. Food Waste Effluent

Because food waste effluent can contain a substantial portion of organic contaminants, such as BOD, COD, DO, and TSS, microbiology and sanitary testing parameters for this water type play an important role [14,31]. Organic content provides food for microorganisms, consumes oxygen, and interferes with disinfection [35]. Table 3 presents the main sanitary results for the food waste effluent.

Table 3. CS2 intervention three food waste effluent sanitary testing results (2015–2016).

Raw Food Waste Effluent Tested by Location and by Date	pH	BOD (mg/L)	DO (mg/L)	TSS (mg/L)	TDS (mg/L)	Residual Chlorine (mg/L)
Hotel A 1 December 2015 [24]	3.54	18	-	10	84	-
University 1 May 2016 [24]	3.15	65	5.7	<6	190	0.03
Hotel B 4 May 2016 [24]	3.02	5	5.3	8	308	<0.02
MFCS 22 September 2016	2.7	57,200	-	10	706	-
MFCS 26 September 2016	4.8	42,400	-	<6	452	-
MFCS 29 September 2016	3.11	52,460	-	10	690	-
MFCS 4 October 2016	3.98	10,200	-	<6	242	-
MFCS 3 November 2016	3.68	405	4.5	-	180	0.12
MFCS 22 November 2016	3.76	105	4.5	-	120	0.12
MFCS 29 November 2016	3.84	405	4.5	-	210	0.14
MFCS 06 December 2016	2.86	-	4.5	-	160	0.12
MFCS 7 December 2016	2.81	655	-	-	-	-
MFCS 8 December 2016	2.48	1260	-	-	-	-
MFCS 14 December 2016	2.37	805	-	-	-	-
RSB recommended values for water recycling [26]	6 to 8	10	⩾1	10	-	0.5 to 1
Duncan et al. recommended values [14]	6.5 to 8.4	-	-	-	<960	<1
US EPA recommended values [31]	6 to 9	⩽10				<1

The pH in all samples was very acidic, scoring as low as 2.7, with the highest reading being 3.98, below the required 6–8 level recommended by RSB [26]. The TDS level was also below the value recommended by Duncan et al. [14] (see Table A1). Fecal coliforms, intestinal enterococci, and helminth ova microbiology parameters were also tested, and the results were negative in all samples, as outlined in Table 4.

Table 4. CS2 intervention three food waste effluent microbiology testing results (2015–2016).

Raw Food Waste Effluent Tested by Location and by Date	Faecal Coliforms (CFU/100 mL)	Intestinal Enterococci (CFU/100 mL)	Helminth Ova (Number/L)
Hotel A 1 December 2015 [24]	<1.8	non-detectable	non-detectable
University 1 May 2016 [24]	<1.8	non-detectable	non-detectable
Hotel B 4 May 2016 [24]	<1.8	non-detectable	non-detectable
MFCS 3 November 2016	not tested	not tested	non-detectable

MFCS 22 November 2016	not tested	not tested	non-detectable
MFCS 29 November 2016	not tested	not tested	non-detectable
MFCS 6 December 2016	not tested	not tested	non-detectable
RSB recommended values for water recycling [26]	100	40	<1
US EPA recommended values [31]	non-detectable	-	-

After more than 10 tests were performed on the food waste effluent samples from 2015 to 2016, it was evident that this water type would require an advanced level of treatment to be reused at an unrestricted level [31]. According to the laboratory technician, the BOD level of this type of water is site-specific. When the dehydrator was located outdoors (open air location) during the trial test period, the BOD, in some instances (Hotel B, Table 4 above), met the RSB requirements.

3.2.2. Fire Sprinkler Pump Test Water

The water used for the fire pump test of the sprinkler system was tested in March 2017. Two samples were drawn on 7 March 2017. The first sample was collected at 9:15 a.m. and the second approximately five minutes after the first. As evidenced in Table 5, the BOD and the TSS concentrations were higher than the RSB (2010) recommended values for both samples [26], and the TDS concentration was lower than the Duncan et al. recommended value [14].

Table 5. CS2 intervention three fire pump sprinkler test water quality sanitary results (2017).

Fire Pump Test Water Tested by Location and by Date	pH	BOD (mg/L)	DO (mg/L)	TSS (mg/L)	TDS (mg/L)	Residual Chlorine (mg/L)
Sample one (7 March 2017)	7.99	27	5.6	56	106	0.02
Sample two (7 March 2017)	8.05	19	5.7	38	98	<0.02
RSB recommended values for water recycling [26]	6 to 8	10	⩾1	10	-	0.5 to 1
Duncan et al. recommended values [14]	6.5 to 8.4	-	-	-	<960	<1
US EPA recommended values [31]	6 to 9	⩽10	>5	-	-	<1

However, it is interesting to note that, after approximately five minutes, the levels of BOD, TSS, TDS, and residual chlorine decreased significantly, making the pH more alkaline. Table 6 provides some of the microbiology results for the FPSTW in colony-forming units per liter (CFU/L). Results not shown here include the total coliforms, *Escherichia coli*, and fecal streptococci, which were non-detectable, and *Pseudomonas aeruginosa* and Legionella in CFU/L, which were less than 1 (<1). The turbidity also showed levels higher than required at 24 nephelometric turbidity units (NTU) and 39 NTU for samples one and two, respectively, where the concentration limit was set to five NTU [26].

Table 6. CS2 intervention three fire pump sprinkler test water quality microbiology results (2017).

Fire Pump Test Water Tested by Location and by Date	Faecal Coliforms (CFU/100 mL)	Total Bacterial Count (Heterotrophic Plate Count) (CFU/100 mL)	Helminth Ova (Number/L)
Sample one (7 March 2017)	<1	2100	non-detectable
Sample two (7 March 2017)	<1	1900	non-detectable
RSB recommended values for water recycling [27]	100	-	<1
US EPA recommended values [32]	non-detectable	-	-
World Health Organization [3]	-	<500	-

The total bacterial count in both samples was higher than the World Health Organization recommended limits [36], which confirms that this water type would need tertiary treatment to avoid bacterial regrowth if reused at an unrestricted level [31].

3.2.3. Reverse Osmosis Reject Water (RORW)

The RO reject water was sampled in June 2017, at which time the RO unit for the steam boiler was newly installed. The results (Table 7 below) show that the TDS was extremely low; this is unusual for this type of water, as was noted by the interviewed laboratory technician [3]. The TDS level of this water type in the region generally ranges from 100 mg/L to 300 mg/L [3]. It was concluded that the RO systems may not have been commissioned when the water was sampled. The operator subcontractor who was managing laboratory testing for both units shared their testing results, which provided evidence that the TDS level is 320 mg/L. The other sanitary parameters meet the RSB requirements (Table 7).

Table 7. CS2 intervention three ro reject water sanitary testing results (2017).

Reverse Osmosis Reject Water Tested by Date	pH	BOD (mg/L)	DO (mg/L)	TSS (mg/L)	TDS (mg/L)	Residual Chlorine (mg/L)
3 June 2017	6.4	<3	6.2	<6	7	<0.02
October 2017 tested by others	7.1	-	-	-	320	-
RSB recommended values for water recycling [26]	6 to 8	10	⩾1	10	-	0.5 to 1
Duncan et al. recommended values [14]	6 to 8	-	-	-	<960	<1
US EPA recommended values [31]	6 to 9	⩽10	-	-	-	<1

Table 8 provides evidence that the microbiology results meet the RSB and US EPA requirements and recommendations.

Table 8. CS2 intervention three ro reject water microbiology testing results (2017).

RORW Tested by Date	Fecal Coliforms (CFU/100 mL)	Total Bacterial Count (Heterotrophic Plate Count) (CFU/100 mL)	*Pseudomonas aeruginosa* (CFU/100 mL)
3 June 2017	<1	1500	non-detectable
RSB recommended values for water recycling [26]	100	-	<1
US EPA recommended values [31]	non-detectable	-	-
World Health Organization [36]	-	<500	-

The total bacterial count of the RO reject water is also high, which means this type of water may also need a tertiary treatment system. Yet, the total coliforms, *Escherichia coli*, fecal streptococci, and *Pseudomonas aeruginosa* in CFU/L were less than 1 (<1), below the RSB recommended values. Helminth ova were not tested for financial reasons.

3.2.4. Heavy Metal Results for All Non-Potable Water Types

Table 9 below provides evidence that the food waste effluent has levels of copper and aluminum that exceed the RSB requirements. Results not shown here also indicated that levels of other metals, such as arsenic, beryllium, cadmium, chromium, cobalt, iron, lead, lithium, nickel, and vanadium, are within the RSB limits for all water types tested. Table 9 provides evidence that the heavy metal content is within RSB requirements for the FSPTW, the CE, and for the RORW.

Table 9. CS2 intervention three main heavy metal test results for non-potable water (2016–2017).

Non-Potable Water Types	Cadmium (mg/L)	Copper (mg/L)	Zinc (mg/L)	Aluminium (mg/L)	Selenium (mg/L)	Cobalt (mg/L)
Treated condensate water (2017)	<0.002	<0.002	<0.001	<0.005	<0.001	<0.02
Raw fire sprinkler pump test wastewater (2017)	<0.002	<0.002	<0.001	<0.005	<0.001	<0.002
Raw reverse osmosis reject water (2017)	<0.002	<0.002	<0.001	<0.005	<0.001	<0.002
Raw food waste effluent wastewater (October 2016)	<0.002	0.553	0.458	9.30	0.042	<0.002

In terms of water quality monitoring, trace elements (such as iron, manganese, zinc, copper, and nickel) need to be checked when reusing recycled water such as condensate, RORW, food waste effluent, and/or FSPTW for irrigation. Not all trace elements are toxic, and, in small quantities, the ones cited above are essential for plant growth [14].

In 2017, after the soil was amended, the exchange capacity (CEC) improved, but the ratio of calcium to sodium of the irrigation water was still uncertain, which directed the research toward the water quality. Only continuous and regular soil and water testing can identify the most economical solutions (either through soil or water amendment) to regulate non-potable water, such as ultrapure water, for reuse.

3.3. CS2 Intervention Three Non-Potable Water Treatment Risk Assessment

As discussed above in Sections 3.2.1–3.2.4, it was found that the CW, FSPTW, and RORW require tertiary treatment for unrestricted reuse because bacterial counts are still high prior to secondary treatment.

In 2017, to simplify and reduce the cost of maintaining and operating the treatment system and to make it more efficient, the multimedia sand filtration (primary treatment) and sodium hypochlorite injection system (secondary treatment) were decommissioned. The primary treatment system was deemed unsuitable (by Culligan contractors and Cardno Consultants) for the CW. This was also confirmed verbally to the author by the RSB wastewater manager during a meeting in 2016. The sodium hypochlorite injection system was originally connected to both the LI and WF systems, which posed two problems. Firstly, it was designed to inject chlorine into both the WF and the irrigation system. Secondly, a license was needed to operate this system, which was never granted for the MFCS hospital by the RSB and Environment Agency—Abu Dhabi (EAD).

Figure 4 illustrates the changes for CS1 Intervention One (discussed in Seguela et al. [3]) and CS2 Intervention Three. The MFCS hospital is left with two tertiary treatment systems in addition to the existing limestone contactor (secondary treatment) and a newly installed ultraviolet (UV) filtration and disinfection system. The latter serves the irrigation system, which, prior to this change, had no tertiary treatment system. The WF water is treated by the existing ozone/chlorine tertiary treatment system, which is currently non-operational because it has not been commissioned but forms part of the non-potable water treatment system enhancement scope.

Figure 7 shows CS1 Intervention One (discussed in Seguela et al. [3]) and CS2 Intervention Three. The photographs show the UV treatment system location before and after the system was installed. They also show the new connection between the two tanks (T41-1 and T42-1), which helps to avoid 'dumping' excess CW to sewage. The CW flow meters are also shown; these were installed at the exit of the raw condensate water tanks and calibrated in January 2017 and January 2018.

Figure 7. CS1 intervention one non-potable system enhancement results.

3.4. Water Resources Implications and Risks Summary

Table 10 provides a summary model summarizing the non-potable water resources' implications and risks.

Table 10. Water resources reuse and risks summary.

Water Resources and Associated Issues	Implications for the Audience Target	Risks
Condensate water, RORW, FSPTW	Monitor quantities for reuse by flow metering	Water wastage
Non-potable system including all non-potable water types	Provide sufficient long-term storage at design stage preferably to minimize cost	Water wastage
	Water system automation	
Condensate water, FSTW, RORW	Reuse for LI and WFs providing it is going through a tertiary treatment system	BOD, bacterial counts, and Legionella prevention
WF water chemical treatment	Treatment system automation	Environmental pollution and human health impact
Water conservation training and awareness	Wastewater treatment technician and mechanical engineers to receive quarterly refresher training on water quality requirements, testing, and chemical dosing monitoring	Environmental pollution

4. Discussion

CS2 Intervention Three (A/C condensate water and additional non-potable water quality testing) was completed in March and June 2017, including the testing and analysis of the four different types of non-clinical/non-potable water source available onsite: A/C CW, FSPTW, RORW, and food waste effluent. It was found that the CW falls into the rainwater category (i.e., an ultrapure water type), whereas the RORW and FSPTW fall under the process/industrial water category. While all these water types have similar water treatment requirements, the two latter have higher salinity than the CW.

4.1. Interpretation of the Findings

4.1.1. MFCS Alternative Response: Water Demand

The findings described above provide evidence that the MFCS hospital is wasting CW by using an excess of desalinated makeup water. Figure 8 gives an account of the total outdoor water demand after Seguela et al.'s WF demand calculations, irrigation rate implementation, and soil amendment [37,38] compared with the available CW supplied in 2017 (EMCS records). The water balance outcome (Figure 8) provides evidence that a CW deficit (of 929.63 m^3) should only be occurring in February rather than the current seven months (as of January 2018).

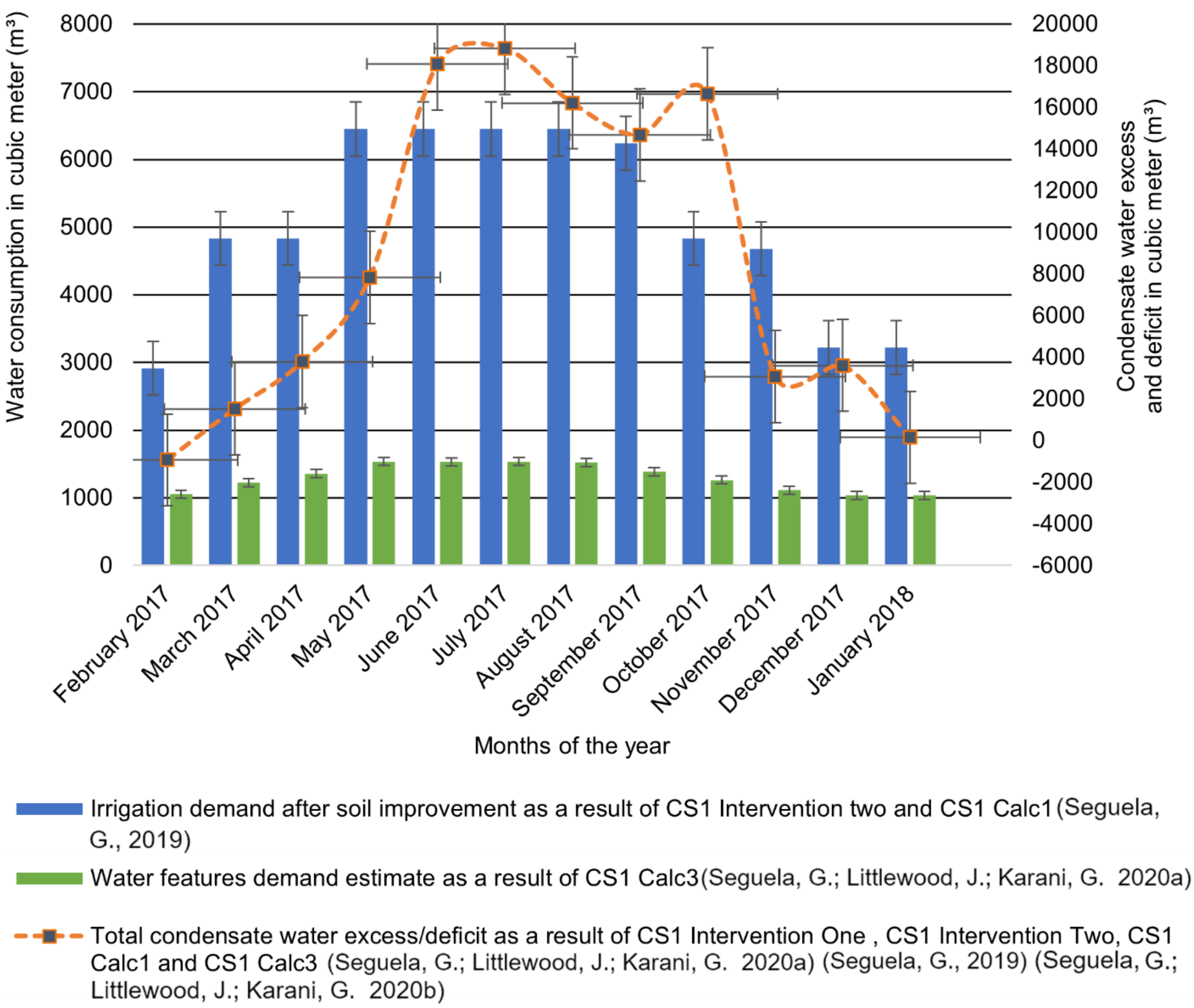

Figure 8. CS1 intervention one water balance based on cs1 calc 1 and cs1 calc3 against available condensate water supply [1,2,25].

4.1.2. MFCS Alternative Response: Non-Potable Water Quality

Considering the findings above (Section 4.1.1) regarding the water quality of all types of non-potable water source at the MFCS, it is evident that the non-potable water with the most potential for reuse is the FSPTW and RORW, in addition to the CW. The FSPTW quality is suitable for reuse following tertiary treatment [31]. Based on CS1 Calc2 (additional non-potable water quantity estimate), it would increase existing non-potable water quantities in the winter month of February, which has a lower CW supply; 568 m^3 of FSPTW represents 5.5 days of irrigation in winter, based on CS1 Calc1 (irrigation rate implementation) after soil improvement (CS1 Intervention Two, soil enhancement and valve flow audit implementation) and CS1 Calc3 (water feature water demand).

The AHU A/C CW is the most valuable non-potable water source in terms of quantity produced. The main findings were, firstly, that monthly generation is higher than predicted and, secondly, its characterization as ultrapure water creates challenges for reuse for LI because it has the power to leach essential macronutrients from the soil [14,39,40].

The RORW quality is also suitable for reuse following tertiary treatment. It could increase existing non-potable water quantities by 25,141 m^3 per year. The electrical conductivity of the water (EC) is classified as slight to moderate when it comes to infiltration rate [13]. Ultrapure water also has a greater tendency to corrode pipes than other types of water because of its low EC characteristic [14]. Thus, the RORW could increase the low salinity level of the AHU A/C CW by dilution. This would raise the EC of the CW and, therefore, improve irrigation water quality and decrease piping corrosion risks through dilution in the same storage tank [14,41].

4.1.3. Existing and Additional Non-Potable Water Sources Reuse Potential

Figure 9 below totalizes all the potential non-potable water sources available onsite, including the total CW supply as recorded by the EMCS in 2017 and the estimated quantities of RORW and FSPTW based on CS1 Calc2 (additional non-potable water quantity estimate). When all available non-potable sources were totalized against 2017 EMCS records for LI and WF water consumption, the deficit (4644 m³) is limited to one month (February) as opposed to the current seven months (14,275 m³). When it was totalized against the water demand based on CS1 Calc1 (irrigation rate implementation) and Intervention Two (soil enhancement and valve flow audit implementation) and CS1 Calc3 (water features water demand estimate) [37,38], the supply changed from deficit to surplus.

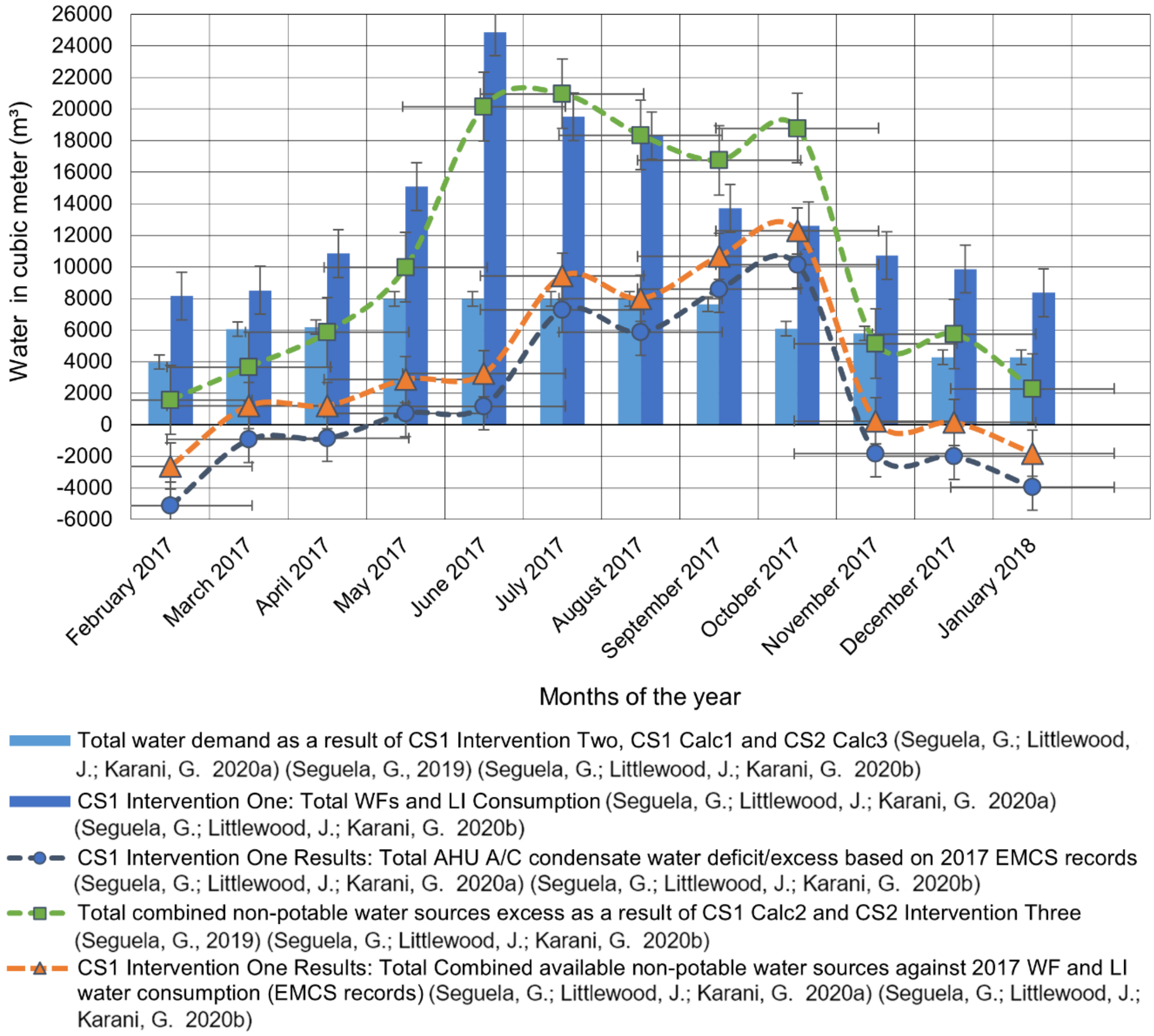

Figure 9. CS1 intervention one water balance based on cs1 calc1, cs1 calc2, cs1 calc3, and cs1 intervention two and three results [1,2,25].

4.1.4. CS2 Water Quality Assessment Outcome

Table 11 provides a summary of the different parameters tested in 2017 for each non-potable water type except for the food waste effluent and provides an average value for 2016 and 2017 testing. The three different types of additional non-potable water generated onsite have the potential to address the CW deficit.

Table 11. CS2 intervention three non-potable water quality testing summary.

Parameters Tested	FSPTW in 2017		Food Waste Effluent Wastewater Average (2015–2016)		Condensate Water in 2017		RORW in 2017		Ayers and Wescot [13]; Duncan et al. [14]
	R	T	R	T	R	T	R	T	Recommendations
Salinity parameters									
TDS (mg/L)	102	-	345	-	35	56	320	-	<960
EC (ds/m)	0.15	-	0.5	-	0.05	0.09	0.5	-	>0.7
Sodium (mg/L)	11.05	-	18.66		3.7	5.8	0.8	-	<200
SAR (meq/L)	0.5	-	1.83	-	0.6	0.4	not detected	-	<6
Macronutrients									Duncan et al. [14]
Calcium (mg/L)	37	-	5.6	-	9	12	not detected	-	20–60
Magnesium (mg/L)	1.7	-	1.5	-	2.6	2.4	not detected	-	10–25
Potassium (mg/L)	1.5	-	-	-	0.8	0.8	not detected	-	5–20
Sanitary parameters									RSB requirements [26]
pH	8	-	3.2	-	7.1	8	6.4	-	6–8
BOD (mg/L)	23	-	16,590	-	3.5	<3	<3	-	<10
DO (mg/L)	5.6	-	4.8	-	7.6	6.5	6.2	-	>1
Microbiology parameters									WHO [36]
Bacterial counts (CFU/100 mL)	2000	-	-		173	<1	1500		<500

Notes: R: raw; T: treated; (-): not tested/not available.

The sanitary parameters of the CW and RORW meet RSB (2010) requirements, whereas the food waste effluent BOD is generally above the maximum 10 mg/L limit. For the food waste effluent to be reused for the WFs and for the sprinkler portion of the LI, an advanced treatment system would be needed [31].

The test results in Table 11 provide evidence that the CW and RORW sanitary and microbiological parameters are similar and meet RSB requirements. The RORW and FSPTW salinity is higher than the CW (as evidenced by the TDS results) but is below the maximum concentrations recommended by Duncan et al. [14] and Ayers and Wescot [13]. Mixing the RORW and FSPTW with the condensate water would increase the total salinity level of the CW by dilution.

The FSPTW was also tested in June 2017. Its BOD is higher than the RSB requirement and higher than the CW. Similarly, to the RORW, the bacterial count for the FSPTW is above WHO-recommended limits for potable water [36]. However, these concentrations could be reduced to the recommended levels once the water passes through the non-potable water tertiary treatment system of the facility (an existing ozone chlorine system for the WFs and a newly installed UV irradiation system for the LI) [31,42,43]. This is clearly shown in Table 11 above, with the bacterial count of the CW decreasing from 173 CFU/100 mL to <1 after going through the limestone contactor secondary treatment system, which can remove 99% of microorganisms [43]. Yet, because waterborne, heterotrophic microorganisms can lead to multiplication or regrowth, disinfection is necessary [44]. The additional tertiary treatment systems would make these water types safe for reuse [31]. In addition, the fire sprinkler pump test occurs at the perfect time when the AHU A/C CW generation is lowest.

4.1.5. Water Quality Assessment in Relation to Soil Quality

In relation to Table 11 above, the US Salinity Laboratory at Riverside California [14] classifies rainwater as ultrapure low electrolyte water; it is extremely low in dissolved salt content, which causes soil infiltration rate problems independent of the soil sodium content measured by sodium absorption ratio (SAR) [14]. CW has similar characteristics to rainwater. When this water type has a SAR between 0 and 3 and an EC < 0.2, its use is severely restricted and should be managed by skilled professionals such as experienced LI managers [13]. The higher the SAR, the more likely water will not infiltrate into the soil. This also depends on the irrigation water salinity [45]. Table 12 provides the EC/SAR relationship.

Table 12. Effects of soil SAR on water infiltration problems at given levels of water salinity (EC) (Flynn [45] p. 7).

SAR of Soil	Potential Water Infiltration Problem	
	Unlikely If EC Is	Likely If EC Is
	Electrical Conductivity (EC) in dS/m	
0–3	>0.7	<0.3
3.1–12	>2.0	<0.5
12.1–20	>3.0	<1.0
20.1–40	>5.0	<2.0

Infiltration is the most important factor in the soil phase of the hydrological cycle [46]. Infiltration rate is a measure of the rate at which soil can absorb irrigation water. Ultrapure-water-fed soil has a lower sodium and potassium content in relation to calcium and magnesium content with respect to soluble ions [40]. This is evident in the results presented in Section 4. The potassium level was moderately low even after solution B application, and the sodium level was particularly low (<40 mg/L) in all samples. The calcium was insufficient in most samples and the magnesium was sufficient in all samples, except in sample two. A characteristic of ultrapure water is its ability to leach sodium and potassium more than calcium and magnesium [13,14,40]. The water results indicate the FSPTW has higher levels of calcium and potassium and a lower level of magnesium than the CW but has better electrical conductivity. The RORW also has a more acceptable salinity level considering the TDS and EC parameters in Table 11 above. Yet, the testing conducted for this water type revealed that the new reverse osmosis unit RO 2 unit was not commissioned when the testing occurred. Therefore, the values tabulated at Table 11 above may not be accurate, except for the TDS and EC, which were provided by the RO 2 manufacturer. Thus, it is observed that the EC level of the RORW is much higher than that of the FSTW and the CW.

In the case of food waste effluent, the infiltration rate can be affected by the accumulation of suspended solids and microbiology activity in the soil [46,47]. It has been shown in the literature that more research is needed on the impact of treated industrial and municipal wastewater on human health and environment due to the presence of heavy metals and pathogens in groundwater when reused for agriculture and LI [47,48]. Heavy metal accumulation, specifically cadmium, copper, and zinc [47], in groundwater can cause problems after long-term reuse [48–51]. This is particularly the case for digested or composted biosolids [52]. Long-term field experiments and close heavy metal monitoring of the soil and non-potable water are essential for obtaining further results and minimizing environmental impact [46,48].

Considering the evidence provided above, the food waste effluent contains high level of copper and aluminum, and the water quantity that could be generated for reuse is extremely small (14.5 m^3/month average or 0.17% of the CW quantity); considering the expense that advanced treatment would incur, this water type was deemed unsustainable for reuse for this project. In contrast, the RORW and FSPTW are ideal candidates for meeting the CW deficit in winter and spring, when CW generation is lowest.

4.2. Contribution One: Case Study Two (CS2) Non-Potable Water Characterization "Fit for Purpose"

CS2 (water quality) Intervention Three (A/C condensate water and additional non-clinical non-potable water testing) and the CS1 Calc2 (additional non- potable water quantity estimate in Seguela et al., 2019c) were initiated by the author in May and July 2016 and in March, June, and September 2017 to increase the non-potable water supply in winter in addition to the existing A/C CW water supply. These three interventions were also initiated by the author to classify and characterize the different types of non-potable water available at the MFCS hospital to understand their impact on the LI, human health, and the building water systems. Three non-potable water types (RORW, food waste effluent, and FSPTW) were tested in addition to the existing A/C CW. The RSB standard does not address these water types for reuse nor does it address the type of water treatment required for LI and WF reuse and their salinity concentration limits [26].

It was found that A/C CW, FSPTW, and RORW require tertiary treatment for unrestricted reuse because bacterial counts are still present prior to secondary treatment. This finding does not align with Cabrera et al.'s statement that "condensate water required minimal treatment" ([19], p. 91). Moreover, Glawe [35], Loveless et al. [15], Bryant and Ahmed [21], Kant et al. [20], Ali Khan and Al Zubaidy [16], and the US EPA [31] addressed NPW quantities and/or microbiological treatment but not the application of NPW, such as CW, RORW, or FPSTW, for LI and WF use and its effect on soil nor its energy and environmental impact on the cited end use on a long-term basis.

Based on the outcome of Case Study Two, our recommendations are:

Firstly, to classify A/C CW under the same category as RORW as both have the same characteristics, except that RORW has a higher EC and SAR. CW, which can be classified as ultrapure water, can be stored together with RORW, which will increase the CW EC and SAR level by dilution. Their level of water treatment (secondary and tertiary) will also be identical to minimize the risk of bacterial content and to ensure that EC and SAR levels are sufficient to prevent piping corrosion and soil infiltration problems. Additionally, when RORW quantity is low, CW will need to be amended so that the EC and SAR levels are sufficiently high to avoid affecting soil infiltration.

Secondly, to classify food waste effluent and FSPTW under the same category, greywater, because their bacterial count is above 500 CFU/100 mL [36]. However, it was found that the food waste effluent has aluminum and copper levels above RSB requirements and, therefore, should not be reused for LI because it could pollute the environment. FSPTW was deemed suitable for reuse for WF and LI subject to treatment through a tertiary system such as ozone/chlorine (for WFs) and UV disinfection (for LI) systems.

4.3. Non-Potable Water Reuse Key Considerations Summary

Table 13 below provides a summary of the key issues that need to be addressed when reusing non-potable water for LI and WFs at an unrestricted level.

Table 13. Non-potable water quality key considerations summary.

Non-Potable Water Types for Reuse for LI and WFs	Key Issues to Consider (See Table A1 for Non-Potable Water Reuse Recommendations Limits and Quality Risk Assessment)	Impact			
		Soil Infiltration	Pipe Corrosion	Soil Pollution	Human Health
Condensate Water	Test EC, SAR, pH levels, and bacterial counts	X	X		X
RORW	Test TDS, EC, SAR, pH levels, and bacterial counts		X		X
Food waste effluent	Test heavy metals, such as aluminium and copper levels, BOD, pH, and bacterial counts			X	X
FSPTW	Test BOD, TDS, and bacterial counts			X	X

4.4. Limitations: Laboratory Test Methods

The various dehydrator effluent tests undertaken showed a disparity of results, the reason for which is unclear as the same type and quality of food waste was fed into the dehydrator. This condition may be explored in future research.

4.5. Future Work

Figure 10 below illustrates the novel change in practice that occurred at the project site and the proposed changes to occur in the future at the MFCS hospital to operate a treated non-potable water system, as discussed above and in earlier research by the authors [1,3,6]. Non-potable water needs to be treated for microbiological, sanitary, and salinity purposes when being reused at an unrestricted level to protect the public from bacterial exposure and to protect the environment against soil degradation, which is a major aspect of decarbonization, and to ensure piping and associated components are not affected by corrosion.

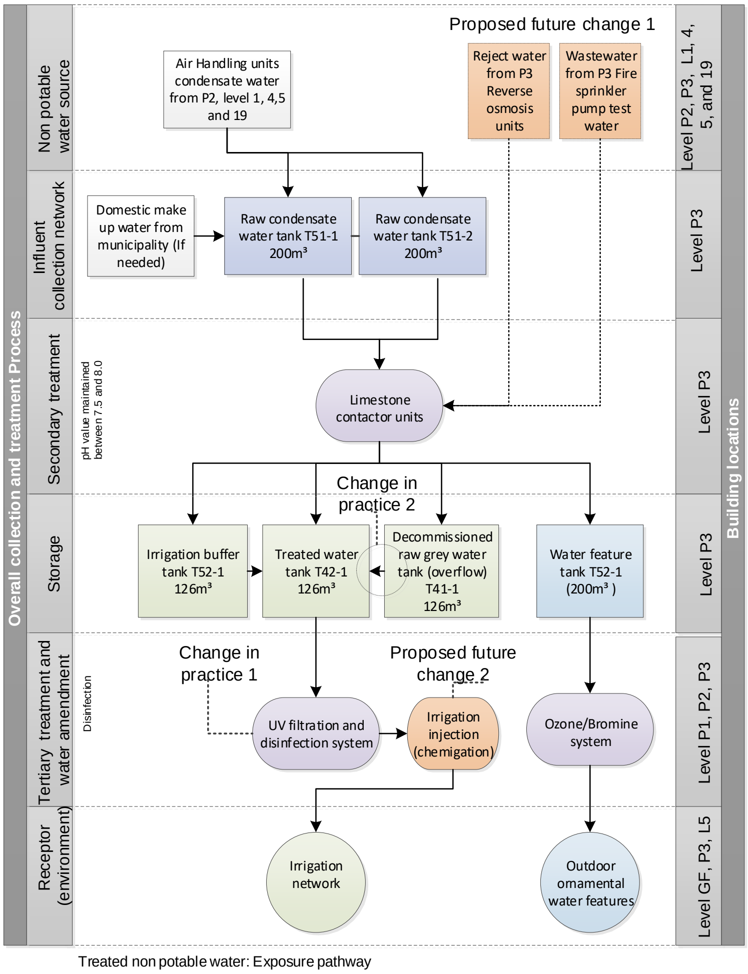

Figure 10. CS2 intervention three, contribution to professional practice: water treatment exposure pathway.

A water amendment, such as chemigation, may be more appropriate for the MFCS to counteract the low salinity of the condensate water and to save on the cost of manpower and time of application.

5. Conclusions

The authors developed two case studies to establish a non-potable water supply and a water demand strategy to achieve zero use of desalinated water for LI and WFs, to increase the non-potable water supply in winter, in addition to the existing A/C CW water supply, and to minimize operation costs, energy consumption, and GHG emissions without compromising water quality.

This paper focused on CS2 (NPW quality testing), a water supply strategy based on an action research methodology for minimizing the use of both desalinated water and NPW for LI and WFs to decarbonize the use of water.

The results of CS2 were discussed, which focused on the quality of alternative non-potable water demand. The water supply strategy includes included CS2 Intervention Three as the testing and analysis of four sources of non-potable water generated at the MFCS through mechanical processes to increase the non-potable water supply in winter and spring when AHU A/C CW generation is low.

These interventions also classified and characterized different types of non-potable water available at the MFCS to understand their impact on LI, human health, and the building water systems. Three non-potable water types (RORW, food waste effluent, and FSPTW) were tested, in addition to the existing AHU A/C CW. It was found that A/C CW, FSPTW, and RORW require tertiary treatment for unrestricted reuse because bacterial counts are still present.

These three different types of additional non-potable water generated onsite have the potential to address the CW deficit. The AHU A/C CW is the most valuable non-potable water in terms of quantity. Monthly generation was higher than predicted, but its characterization as ultrapure water creates challenges for reuse for LI as it can leach essential macronutrients from the soil. The RORW and FSPTW fall into the process/industrial water category. While all three have similar water treatment requirements, the two latter have higher salinity than the CW.

The RORW quality is also suitable for reuse following tertiary treatment. Ultrapure water also has a greater tendency to corrode pipes than other types of water because of its low EC. The RORW could counter the low salinity level of the AHU A/C CW by dilution. This would raise the EC of the CW, improving suitability for irrigation and reducing piping corrosion risks through dilution in the same storage tank.

The sanitary parameters of the CW and RORW meet RSB (2010) requirements, whereas the food waste effluent BOD is generally above the maximum of 10 mg/L. This means an advanced treatment system would be needed for the food waste effluent to be reused for WFs and the sprinkler portion of the LI.

Non-potable water does need to be treated for microbiology, sanitary, and salinity purposes when reused at an unrestricted level to protect the public from bacterial exposure and to protect the environment against soil degradation, which is a major aspect of decarbonization, and to ensure piping and associated components are not affected by corrosion.

The water supply strategy can be extended to any commercial buildings design in AD because most buildings are equipped with an AHU A/C CW system and a fire sprinkler system. However, commercial buildings may be more limited than healthcare buildings in meeting the CW deficit in winter since RO is mainly used for chirurgical equipment sterilization and is, thus, specific to hospitals.

To minimize the water and energy consumption associated with GHG emissions for LI and WF use, the following changes in practice are required:

1. The RSB standard should address these water types for reuse, the type of water treatment required for LI and WF reuse, and their salinity concentration limits;
2. Food waste effluent should not be reused for LI because it has the potential to pollute the environment due to heavy metal content;
3. Healthcare buildings designed with a RO system should recover, store, and treat RORW (with a TDS < 500 mg/L) for reuse for either LI and/or outdoor WFs use. The RORW quantities generated must be calculated before a recovery system is installed considering an additional pump will need to be installed to convey the recycled reject water to the water storage tank;
4. To monitor and measure quantities of RORW and FSPTW, flow meters should be installed at the exit of the water reservoir tanks or at the exit of the system’s line;
5. Buildings should recover and treat FSPTW for LI and/or outdoor WFs use;
6. NPW treatment systems should be selected “fit for purpose” to maximize operational cost and minimize impact on human safety and the environment.

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Appendix A. CS2 Intervention Three Non-Potable Water Evaluation

Table A1. CS2 Intervention Three Non-Potable Water Evaluation: Updated Water Recycling Recommendations Limits from Seguela et al. [25]

Nutrient Guidelines in Irrigation Water (mg/L), Duncan et al [14]						
Nutrient Parameters	**Symbol**	**Units**	**Low**	**Normal**	**High**	**Very High**
Sulfur	S	mg/L	<10	10–30	30–60	>60
Amonium	NH_4^-	mg/L	<2	2–75	75–100	>100
Sulfate	SO_4^{-2}	mg/L	<30	30–90	90–180	>180
Nitrate	NO_3^-	mg/L	<5	5–50	50–100	>100
Calcium	Ca	mg/L	<20	20–60	60–80	>80
Magnesium	Mg	mg/L	<10	10–25	25–35	>35
Potassium	K	mg/L	<5	5–20	20–30	>30
Nitrogen	N	mg/L	<1.1	1.1–11.3	11.3–22.6	>22.6
Phosphorous	P	mg/L	<0.01	0.1–0.4	0.4–0.8	>0.8
Reclaimed Water Guidelines (mg/L), Duncan et al [14]						
Salinity Parameters	**Symbol**	**Units**	**Recommended Maximum Values**		**Desired Range**	
Electrical Conductivity	EC	ds/m	1.5		0.40-1.20	
Sodium	Na	mg/L	200		<70	
Chloride	Cl	mg/L	250		<70 (root injury/foliage uptake injury) <100 (if sprinkler used on foliage)	
Boron (micronutrient)	B	mg/L	0.5		<0.5	
Bicarbonate	HCO_3^-	mg/L	250		<120; <90 (if sprinkler used on foliage)	
Total Dissolved Solids	TDS	mg/L	960		256-832	
Sodium adsorption ratio	SAR	meq/L	5.7		<6	
Irrigation Criteria for Trace Elements (mg/l), RSB [26,53]						
Trace Elements	**Symbol**	**Units**	**Maximum Allowable Concentration**			
Alumnium	Al	mg/L	5			
Arsenic	As	mg/L	0.1			
Beryllium	Be	mg/L	0.1			
Cadmium	Cd	mg/L	0.01			
Chromium	Cr	mg/L	0.1			
Cobalt	Co	mg/L	0.05			
Copper	Cu	mg/L	0.2			
Fluoride	F	mg/L	1			
Iron	Fe	mg/L	5			
Lead	Pb	mg/l	5			
Lithium	Li	mg/L	2.5			
Manganese (micronutrient)	Mn	mg/L	0.2			
Molybdenum (micronutrient)	Mo	mg/L	0.01			
Nickel	Ni	mg/L	0.2			
Selenium	Se	mg/L	0.02			
Vanadium		mg/L	0.1			
Zinc (micronutrient)	Zn	mg/L	2			
Microbiology Recycled Water Quality (mg/L), RSB [26,53]						

Microbiology Parameters	Symbol	Units	Maximum Allowable Concentration
Fecal Coliforms	-	CFU/mL	100
Helminths Ova (parasitic worms)	-	CFU/mL	<1
Intestinal Enterococci	-	CFU/mL	40
Sanitary Recycled Water Quality (mg/L), RSB [26]			
Sanitary Parameters	**Symbol**	**Units**	**Maximum Allowable Concentration**
pH	-	-	6 to 8
Biological Oxygen Demand	BOD	mg/L	10
Total Suspended Solids	TSS	mg/L	10
Ammonia Nitrogen	NH4-N	mg/L	-
Total Phosphorous		mg/L	-
Turbidity		NTU	5
Residual Chlorine	CI_2^-	mg/L	0.5 to 1
Dissolved Oxygen	DO	mg/L	≥1

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