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Review Article

Perspectives on Water Utilization in Hemodialysis: Nephrologists' Responsibilities

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Abstract

Background: Hemodialysis is a water-intense procedure, needing large quantities of water for preparation of small volumes of dialysate. The resulting large volumes of reject water is usually discarded. With the rising water crisis both in the United States and the world, it is essential to understand water utilization and identify ways to minimize its utilization and maximize the use of the reject water.

Summary: Unfortunately, water from the city sources cannot be used to produce dialysate unless it undergoes further purification. This results in a large amount of reject water, which can be from 50-70% of total water use, resulting in an enormous waste of resources. A review of solutions for water sustainability is broadly classified into solutions that decrease water utilization and solutions for increased reject water utilization. Those that are aimed at decreasing water utilization were mainly based in innovations in technology – examples are NxStage PureFlow™SL, Aquaboss by Braun and AquaBPlus by Fresenius, and those that focused on increased reuse of RO reject water rely on data that it can be safely utilized for various purposes such as irrigation and flushing toilets. These strategies can be cost-effective. Although the need for sustainability has been recognized there needs to be further awareness and participation among nephrologists to further this cause. In addition, there need to be policies put forward by the government that could encourage sustainability.

Key Messages: Hemodialysis continues to heavily tax the environment. Although the need for sustainability has been recognized, there still remains a lot of work that needs to be done. Further buy-in is needed from all participating entities - nephrologists, dialysis manufacturers and organizations and the government in order to safeguard our limited resources.

Introduction

According to the U.S. Environmental Protection Agency, the average American family utilizes more than 1100 liters of water per day[1]. As a result, the U.S. Government Accountability Office estimated, in 2014, that 40 out of 50 states were expected to develop some level of water shortage in the next 10 years[2]. The individual American water usage is dwarfed by that of the average hemodialysis patient. Evaluation of water utilization in Australia, for example, shows that total water consumption per patient is 408 L/treatment. Accounting for a 20-minute prime and a 30-minute rinse raises the water utilization and may exceed 490L/treatment[3]. The amount of water rejected in the generation of reverse osmosis (RO) water purification was calculated to be around 1.2L/min, or about 350L for a 4-hour session[3]. This rejected water accounts for 70% of the total water utilization which is simply drained and wasted. Data from other sources estimate about 54% of water was discarded and newer generation RO machines discard as little as 20%.[4, 5]

When (not if) these projected global water shortages will turn into a crisis threatening our dialysis patients' care is uncertain, but at its worst, care is likely to be severely compromised. Many international locales already experience such deficiencies. After experiencing the COVID pandemic, most nephrologists recall the tough choices that had to be made when dialytic resources were limited. Such choices might be a reality again, if we remain reckless with our resource consumption. As health care providers, we do not often step back and focus on the world at large, instead of the immediate settings in which we work, and the care of our own patients. In this article, we assess how water is utilized and what developments may help conserve this precious resource.

Water utilization in dialysis

Water, water everywhere and not a drop to drink. An ominous line from Samuel Taylor Coleridge's poem, “The Rime of the Ancient Mariner” rings true for dialysis, irrespective of the modality used. Unfortunately, water purification at the level needed for domestic utilization is insufficient for dialysis. Substances are added at the level of the treatment plant (e.g. aluminum as a flocculating agent and chloramine to prevent bacterial growth) that are harmless to healthy individuals are not safe for dialysis patients. Other substances such as copper and lead can leech from pipes and can result in hemolytic anemia. Microbiological contamination by bacteria and endotoxins can occur at any point from the source of the water to the final dialysis solution. Endotoxins are small enough and cross the dialysis membrane. Toxins from algae that can contaminate municipal water can harm dialysis patients[6]. If healthy individuals are exposed, on the other side of their intestinal epithelium, to 14L per week, hemodialysis patients are exposed to more than 360L per week on the other side of their dialysis membrane. Purification of water is therefore critical to healthy hemodialysis treatments.

In the generation of RO water, water initially passes through a sediment filter and then a water softener that removes calcium and magnesium in exchange for sodium chloride. Then it passes through two granular activated charcoal filters which adsorb organic compounds notably chloramines. Under significant pressure, that water is then pushed across the relatively less-permeable RO membrane, generating the solute-free water needed to make dialysate[7]. In addition, the water softener resins are regularly backwashed to keep the softener resin functioning, requiring additional water volume. The intense RO water process needs to both deionize water and remove organic components. All of this sums up to about 50-70% of the total water needed (lower in new generation RO machines)[3-5], being discarded, for in-center hemodialysis. This does not count the water that is needed for chemical cleaning and disinfection processes, which are required for maintenance of the system.

A study carried out at the University of Alberta to evaluate electricity and water utilization for home hemodialysis machines in Canada observed that around 74% to 87% of water utilized is wasted, with an average total utilization of around 730L for 4 hours treatment with dialysate flow rate (DFR) of 800ml/hr [8].

It is also important to consider that the higher volume of water consumed is associated with higher energy expenditure both at the water treatment plant and the dialysis units. A recent effort to quantitate these variables concluded that the daily power usage by the RO facility at an Australian dialysis unit was 64 kWh, “comparable to the daily usage of 3 average Australian households”[4]. The unit’s daily water usage (7100 m^3) was comparable to the daily domestic usage of 50 average Australians[4]. One estimate of all healthcare’s climate footprint is that it contributes at least 4.4% of global net emission[9].

It is also important to remember that larger water or electricity utilization result in higher overall cost for dialysis which is often passed along to the patient.

In the USA, all dialysis patients are fortunate to be supported by the government to undergo life-saving treatment but such is not the case in less affluent countries. Worldwide it is estimated that the number of people who die prematurely due to lack of renal replacement therapy is three times higher than the number who receive treatment [10]. Global analysis suggests that ≥ 2.3 million people might have died because of the lack of access to this life-sustaining therapy with the disparity being worse in lower and lower-middle-income countries[10]. The largest treatment gaps occurred in low-income countries, particularly in Asia and Africa. In Asia, 17–34% of people needing renal replacement therapy (RRT) received treatment. In Africa, 9–16% of people needing RRT received treatment[11]. By 2030, worldwide use of RRT is projected to more than double to 5.4 million people, with the most growth in Asia[11]. Making hemodialysis less resource-consuming and sustainable could lower costs and these savings could be passed on to patients, with the result that more patients would be able to afford RRT. Sustainability is a need of the present and not just the future.

Progress toward water sustainability

A review of existing literature has revealed a few solutions that have been put forward by the global community. In general, these are focused on two aspects of dialysis – decreasing the use of water and increasing the utilization of reject water. Table 2 summarizes available and possible solutions to optimize water utilization.

i. Solutions with decreased water utilization.

NxStage PureFlow™SL technology is utilized in their Nxstage home hemodialysis systems; it can produce ultra-pure water from ordinary tap water using a deionization technology (DI) with dual bed DI resin redundancies. Home dialysis treatments with the NxStage® System One™ utilizes ~23L per session (calculations were based on 23L/treatments and a total of 21 treatments per month)[12]. In addition to the decreased water utilization, it also minimizes the delivery, storage and inventory needs associated with prepackaged bagged dialysate, making this an attractive technology for sustainability.

Newer generations of water purification systems such as Aquaboss by B.Braun and AquaBPlus by Fresenius are designed to enable water-recovery rates of up 85% in hemodialysis[13, 14]. These manufacturers also claim to be more cost-efficient which will help indirectly push the sustainability agenda.

Data provided by B.Braun show innovation in multiple aspects of hemodialysis to help decrease water utilization. The Aquaboss RO system used to generate dialysate is designed to enable water recover rates up to 85% [15]. Recycling of unused product water and wastewater from secondary RO was estimated to result in 40% less water utilization than conventional systems [15]. The new design no longer needs chemical cleaning and disinfection, instead relying on heat disinfection [15]. This process eliminates the need to rinse out chemicals and results in lower water utilization. The circulation of RO water 24 hours per day, 7 days per week, is no longer required to inhibit bacterial growth, significantly reducing the generation of water utilization; the system can shut down when the unit is closed [16]. Dialog plus hemodialysis machines have automatic standby which conserves water and concentrate usage which saves 113500 liters per device over a year of treatment [16]. B.Braun has also developed the Solocart bicarbonate cartridge which removed the need to have a bicarbonate mixing system, thereby saving the water that would have been needed for the disinfection of this system. Although these are individual plastic cartridges that will need to be recycled, the net water and energy needed to manufacture these cartridges compared to the resource cost of using the bicarbonate mixing system is unclear. B.Braun has also designed a bloodline system – Streamline, which claims to be designed to increase blood flow rates while providing the opportunity to lower dialysis flow rates which would save water while maintaining effective dialysis [17].

Optimization of DFR, when appropriate, focusing on a balance of effective therapy and sustainability would be an effective intervention. DFR is not as important a determinant of hemodialysis adequacy as blood flow rate. At a DFR of 500ml/min, an excess of 24L/treatment of 4 hours is utilized, compared to a DFR of 400ml/min, not accounting for the RO water reject discarded to produce dialysate.

There has been increasing interest in incremental hemodialysis (especially in those with residual kidney function) instead of the cookie cutter thrice a week hemodialysis regimen. Such a strategy might lead to significantly reduced numbers of dialysis treatments, especially in patients who initiate dialysis with residual kidney function. One study from Canada showed over 65% of nephrologists surveyed reported prescribing incremental hemodialysis[18].

There are ongoing studies in the USA to evaluate the effectiveness of such an approach[19]. While data on the effect on mortality and effectiveness are pending, this approach would optimize and perhaps reduce resource utilization.

ii. Solution with increased use of RO reject water.

There are also increasing calls to reuse the RO reject. The RO reject water is currently almost universally discarded. Often, this waste seems to result from conventional or regulatory red tape and is not based on risks associated with the use of reject water.

A comparison of RO reject water to the main water supply and the US EPA standard showed that the RO reject water had higher dissolved salts(with samples testing up to 320mg/L) and conductivity but remained well under the recommended US EPA standards for drinking water [20]. An extract from their comparison is in Table 1. It is important to note that higher total dissolved solutes (TDS) is not a contraindication to reuse of the RO reject. Water with TDS below 1000mg/L can be used for irrigation (higher levels inhibit crop production); between 1000-1500mg/L can be used to flush toilets or wash cars; and for cases where the total dissolved solutes exceed 1500mg/L it could be used after diluting out with rainwater[21]. In Casablanca, Morocco (a country that has significant issues with water shortages) the RO reject water has been used for irrigation of landscapes, public parks, sports fields, and recreational sites[21]. In Fez, Morocco, effluent water is mixed with well water to lower conductivity to make it usable for watering gardens.[22] In Australia, reject water from 2 satellite units was stored in 30,000L storage tanks and this water is then transported by the city to water gardens, cricket pitches, and golf courses. Notably, many of the sporting facilities were under threat of drought-induced closure with training and event cancellation before this water-saving strategy was implemented.[3]. In the outback of Australia, the Kiwirrkurra community stores the RO reject water and uses it to water residential vegetable plots [23].

While implementing new systems to re-use reject water would have considerable upfront costs, data show recovery of initial expenses in a few years and documented profit from reject water utilization. Data from a 173-patient dialysis center in Lyon, France successfully implemented a system that reused 42% of reject water with a return on investment recovered within 5.8 years[24]. A report from the UK on the implementation of a system to recycle RO reject water at a single unit showed a saving of 0.84 tons of CO_2 and a potential annual saving of $13919 with the initial costs for the implementation of the system costing ~$4900[25]. The cost analysis from the study in Morocco for treating the effluents found it to be cheaper (by 30%) and had lower energy demand compared to seawater desalination for landscaping[21]. These examples should serve to push for the implementation of systems for reject water reuse.

Peritoneal dialysis (PD)

The scope of this article does not permit a comprehensive review of the relevant peritoneal dialysis issues, but we briefly note the following. PD utilizes 6-12L of sterile water per day depending on the modality[20]. However, the total amount of water needed to generate those PD fluids has not been disclosed and is protected by commercial confidentiality. Therefore, a thorough life cycle assessment (LCA) has not been performed to date. It would be logical to assume that the process to generate clean sterile water for manufacturing dialysate would be similar to that of hemodialysis, with each individual's requirement for water significantly less. While PD analysis is lacking, one estimate is that PD emissions may be roughly equivalent to "hemodialysis when production and transportation of the large volumes of plastic-enclosed sterile dialysate are considered." [26].

Since waste contains blood-contacted dialysis membranes and dialysis circuits that must be incinerated and landfilled, PD has the advantage that the waste can be included in general waste disposal at home. The environmental effects of HD and PD may be dramatically different [27].

Acute Kidney Injury

Another topic of a presumably smaller magnitude is that of acute kidney injury (AKI). Whether treated by frequent intermittent hemodialysis or by continuous renal replacement therapy, the water requirements of these modalities are substantial. The environmental consequences of the application of the therapeutic options have barely been considered in the literature. However, a recent review discussed the rationale for PD for AKI as “a more resource and environmentally efficient treatment with the potential to improve dialysis access, especially to vulnerable populations, including women and children, in lower-resource countries.” [28] .

Areas of need

The need for sustainability in kidney care has been recognized. The Global Environmental Evolution in Nephrology and Kidney Care – the GREEN K initiative – was established by the International Society of Nephrology, comprised of representatives from nephrology societies around the world. It is focused on promoting environmentally sustainable kidney care. The GREEN-K initiative advocates for, and educates about, green nephrology with the goal of reducing the specialty's carbon footprint[29]. Its goals include the encouragement of manufacturers of dialysis equipment to innovate in a timely fashion, in order to facilitate the procurement of climate-resilient kidney care systems by dialysis facilities. The healthcare and nephrology communities must recognize the urgent necessity of global environmentally sustainable kidney care. GREEN-K and ISN propose pathways to achieve these goals through a global, collaborative, and inclusive multidisciplinary working group.

An avenue that needs further work is the awareness and participation of nephrologists in sustainable endeavors. A multinational survey of healthcare professionals on the interconnectedness of climate change and kidney health showed that while most participants believed that climate change is happening, only 14% were involved in climate change and kidney health initiatives (membership, knowledge/awareness, research, and advocacy), 22% in sustainable kidney care initiatives (education/advocacy, preventative nephrology, sustainable dialysis, promoting transplant/home therapies, and research)[30]. The latter is concerning because the questions, despite not solely limiting themselves to new sustainability initiatives, also involved what should be considered good practice. The lack of buy-in by nephrologists is an issue that needs to be addressed. As nephrologists and medical directors of dialysis centers, we are in a unique position to lobby for better utilization of our water resources and push for reuse of the RO reject. With enough momentum lies an opportunity to pressure large dialysis companies (who have the majority stake in dialysis operations in the USA) to implement sustainable initiatives and to innovate new sustainable technologies.

Life cycle assessment (LCA) is a technique which can be applied to the fields of kidney replacement therapies. Figure 1 depicts an example of LCA, including life cycle impact assessment (LCIA) [31]). LCA involves a comprehensive analysis of the environmental impacts of products or technologies, including extraction of raw materials used for manufacturing, followed by distribution, use, repair, maintenance, disposal or recycling [32].

A thorough LCA would produce an analysis of the composition and volume of wastewater and plastic waste generated using dialytic modalities and consider how kidney replacement therapies could engage in reduction and recycling. The data for LCAs can be generated by more comprehensive monitoring than has routinely been applied to date. For example, in a recent LCA of hemodialysis, focused on a goal of decarbonization, it was estimated that hemodialysis led to greenhouse gas emissions of about 12.8 tons of CO_2 equivalents per person in the United Arab Emirates annually [32] . Data monitoring required to routinely assess power and water utilization and waste generation is difficult to deploy widely. Such data gathering could be considered a worthy goal of dialysis units in the future. It would potentially lead to more environmentally responsible application of technologies. Detailed LCAs can also guide manufacturers to improved sustainability targets for innovations in dialytic techniques. One goal of the GREEN-K initiative is to apply such data and knowledge to “procurement”, meaning to make demands of the manufacturers regarding our “green” and sustainable needs.

The alternative is a top-down approach where sustainability needs to be driven by governmental policies. This has often been frustrating, getting certain members of political parties to admit to the existence of climate change has been horrifyingly challenging. Even more detrimental to the efforts of this change is that the concept of wokeness has been tagged to sustainability[33]. This has resulted in the support for sustainability falling along political party lines instead of being a national concern supported by all. Water shortages might be an easier pill to swallow even among those resistant to sustainability as it is now a reality to those living in states like Texas or California where the government on both sides of the political spectrum had to step in to restrict water utilization by the public.

Policy changes are necessary to move us to a more sustainable future. Here we offer a few thoughts to guide them as follows:

All dialysis patients in the US are supported by Medicare. The US Government via Medicare should place incentives to encourage hemodialysis centers to implement sustainable technology. Phasing out the older RO machines would be beneficial for the general ecology. Centers throughout the world particularly in areas that are challenged with respect to water supplies could also utilize these modalities, albeit at significant expense.

Dialysis centers could join in making water treatment and utilization of reject water more financially viable. Governmental involvement could facilitate reject water utilization from stand-alone dialysis centers and policies for more reject water utilization at the state and federal level should be implemented, at least in areas with projected water stress.

There need to be systems in place to track resource utilization (water and electricity) in the healthcare sphere. This measurement would help in identifying resource-hungry aspects of treatment and the ability to monitor the results of implementation of solutions[4]. Such measurements were recently demonstrated to be feasible in an Australian hemodialysis program. Having long term data on resource utilization would be essential for understanding trends, projecting future utilization requirements, and optimizing resource utilization.

Policies at the state or federal level could push more aggressively for home dialysis, especially in places with water shortages.

More funding could be allocated to sustainability research. The National Institutes of Health (NIH) and other international research programs should encourage sustainability research.

There should be sustainability incentives for insurance companies to promote good clinical practice to diminish the progression of chronic kidney disease and keep patients from initiating dialysis.

Some approaches might be more expensive to implement but we must remember that resource utilization and energy consumption are not free, as we bill the future for it.

Conclusions

We are a long way from where we need to be and the implementation of corrective actions is delayed and fraught with challenges at every turn. Change seems a must and now is a good moment to put nephrology under the spotlight to understand our contribution to the environmental burden and what we can do to advocate for a better world for all without compromising on our commitment to our patients. Unfortunately, there is a discrepancy between the countries with the greatest need for resource optimization and sustainability and those nations with the ability to drive innovation. Given that the US, China, and the collective European Union contribute to more than 50% of the world's medical carbon footprint, those of us practicing in these countries to have a greater urgency to push for sustainability[9]. Every step that gets us closer to sustainability saves lives both now and in the future.

It is essential that we involve those training in nephrology and acclimatize them to their responsibility to the world at large. As nephrologists, we are not strangers to the idea that disease is often influenced by a multitude of factors in the patient's life. We must start to consider our environment as one that affects our patients. There is a need to train a generation of environmentally conscious nephrologists who will continue to advocate for sustainability knowing that taking care of the world undoubtedly takes care of our patients.

We hope this essay serves as a reminder that there is a crisis ahead and both the nephrologists and our ESKD patients are bound to be affected. We need both innovation and careful review of our resource utilization now to mitigate the effects of a parched future.

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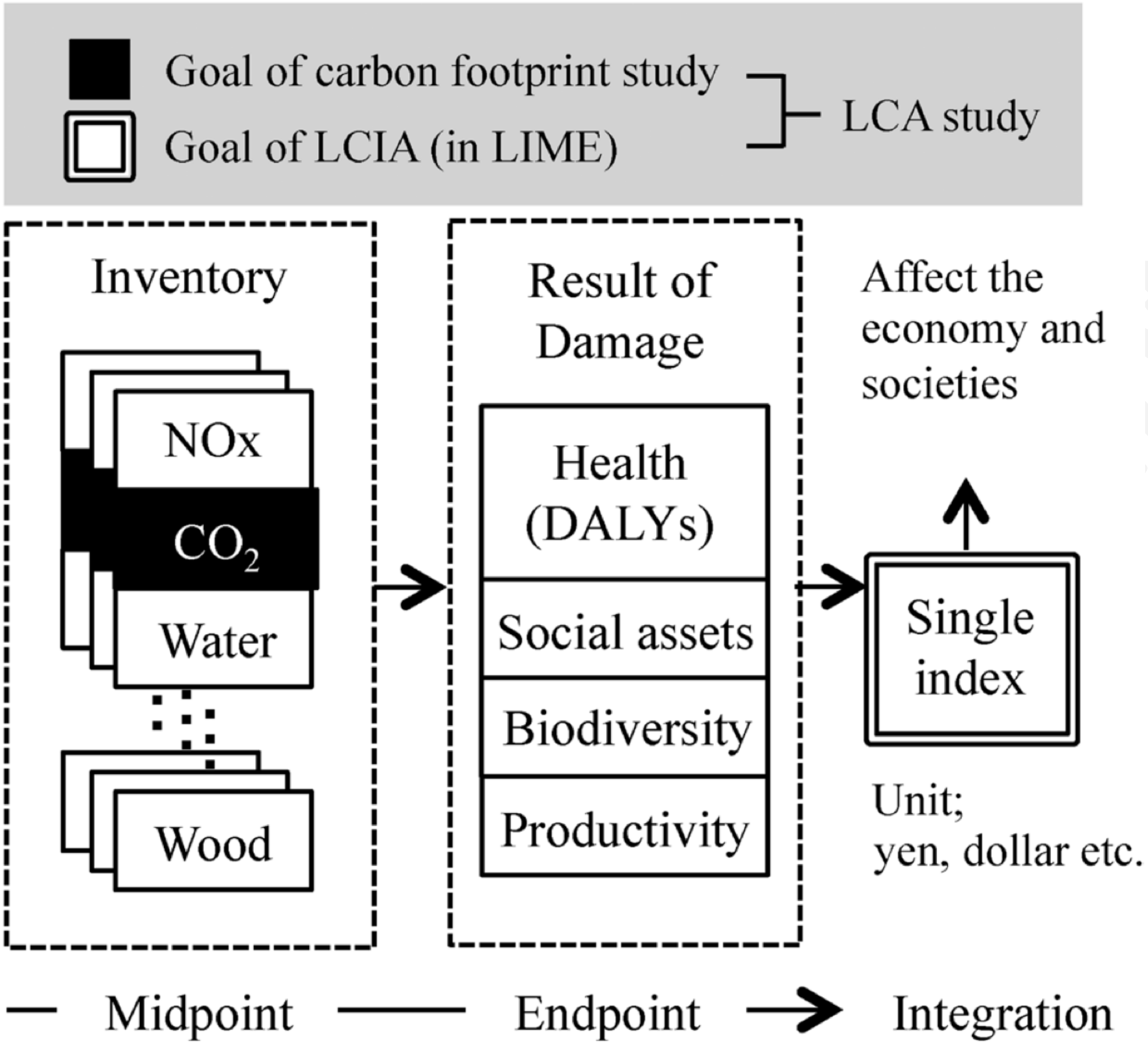
Figure Legends

Figure. 1.Concise diagram of life cycle assessment and life cycle impact assessment. Most life cycle assessment studies have quantified CO2 emissions relating to various human activities, including healthcare. Beyond midpoint investigations such as carbon footprint counting, life cycle impact assessment (LCIA) depicts the actual impacts on humans and natural ecosystems based on human activity and industry. Quantification of detrimental health effects, social asset loss, destruction of biodiversity, and reduction in productivity such as photosynthesis are integrated into a single index to clearly show the environmental burden of human activity. Monetary evaluations (e. g., yen and dollar) have the potential to motivate private companies and societies to reduce greenhouse gas emissions using market mechanisms. Abbreviations: LCA, life cycle assessment; LCIA, life cycle impact assessment;

LIME, life cycle impact assessment method based on endpoint modeling; DALYs, disability-adjusted life years. From Negai et al. Assessment of environmental sustainability in renal healthcare [31].


Goal of carbon footprint study
Goal of LCIA (in LIME)
LCA study
Inventory
NOx
CO_2
Water
Wood
Result of Damage
Health (DALYs)
Social assets
Biodiversity
Productivity
Affect the economy and societies
Single index
Unit;
yen, dollar etc.
Midpoint
Endpoint
Integration

Analyte	Units	Main water to HD1	RO RW from HD1	Main water to HD2	RO RW from HD2	<US EPA standard for drinking water
Aluminum	mg/l	0.01	0.01	0.01	0.01	<0.05
Copper	mg/l	0.021	0.009	1.3	0.01	<1.3
Iron	mg/l	0.05	0.02	0.02	0.02	<0.3
Lead	mg/l	0.002	0.001	0.003	0.002	<0.015
Mercury	mg/l	0.0001	0.0001	0.0001	0.0001	<0.002
Calcium	mg/l	8.4	0.1	8.3	0.1	No std
Sodium	mg/l	34	140	33	68	<200
Total hardness	mg/l	43	0.1	43	0.1	No std
Chloride	mg/l	60	150	61	74	<250
Sulfate	mg/l	9.4	23	9.5	11	<250
Dichloramine	mg/l	0.1	0.1	0.1	0.1	<0.8
Conductivity	µS/cm	280	680	280	340	<2500
pH	pH units	7.3	7.5	7.3	7.5	7.5±1.0
Dissolved solids	mg/l	110	320	190	200	<500

Table 1: Assay results for water contaminants in mains water in-feed and RO system reject water outflow

Abbreviations: HD1, eight-station hospital in-center dialysis unit; HD2, 16-station suburban satellite dialysis facility; MPN, most probable number; NTU, nephelometric turbidity units; org; RO RW, reject water from outflow port: centralized in-center unit reverse osmosis system; Data derived from Agar et al, 2015 [12].

Existing solutions to improving water utilization
A. Solutions for decreased water utilization 1. Improved technology ▪ NxStage PureFlow™SL technology is utilized in their Nxstage home hemodialysis systems ▪ Newer generations of water purification systems such as Aquaboss by B.Braun and AquaBPlus by Fresenius ▪ Improved dialysis components such as the Solocart and bloodline system by B.Braun 2. Optimalization of Dialysis flow rates 3. Consider incremental hemodialysis when able B. Solutions for increased use of reject water Irrigation, flush toilets, wash cars, etc.
Solutions that need further work
A. Increased awareness and participation of nephrologists in sustainable endeavors B. Governmental involvement in more sustainable policy changes to improve water utilization
Table 2: Summary of solutions for improved water utilization in dialysis