

Water conservation and circular water reuse in clinical hemodialysis facilities: a scoping review

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Abstract

Introduction.

Hemodialysis is a life-sustaining but resource-intensive therapy with a substantial water footprint, estimated globally at 270 billion litres annually and approximately 78,000 L per patient. Green dialysis strategies increasingly focus on reducing dialysate flow and reusing reverse osmosis reject water; however, evidence remains dispersed across clinical studies, service reports and feasibility analyses. This scoping review mapped and synthesised literature on water conservation and reuse strategies in hemodialysis.

Methods.

A scoping review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines and registered with the Open Science Framework. PubMed, EMBASE, Web of Science, Scopus and CINAHL were systematically searched. Extracted data included study design, setting, participants or dialysis service characteristics, water use measures, reported water savings, safety, and environmental or operational outcomes.

Results.

Fourteen studies were included: nine dialysate flow modification studies and five reject water reuse studies. Reported water savings ranged from 24 L/hemodialysis session to 162.3 L/treatment. Reducing dialysate flow from 500 to 300 mL/min saved approximately 48 L/session without major short-term compromise in dialysis adequacy. Reusable volumes ranged from > 250 L/session to 1.1 million m³/year nationally. Facility-level reuse ranged from approximately 1.2–4.5 million L/year per centre, with applications including sanitation, autoclave steam generation, horticulture, aquaponics and agricultural irrigation.

Conclusion.

Water conservation in hemodialysis is achievable through reduced dialysate flow and reject water reuse. Evidence is primarily single-centre and heterogeneous; further standardized reporting and long-term clinical, operational and implementation studies are needed.

Introduction

Water scarcity, defined by the United Nations as a lack of sufficient water resources to meet the basic needs of people, including drinking, sanitation, hygiene and food production, is a critical global issue affecting billions of people (United Nations Children's Fund 2026; United Nations Water 2026b). According to the World Health Organisation (WHO), around 2.2 billion people lack access to safe drinking water and 4.2 billion people lack access to safely managed sanitation services (Osseiran and Lufadeju 2019). Water scarcity is not only a problem in arid and semi-arid regions, but in areas with high population densities, inadequate infrastructure and poor water management practices (United Nations Water 2026b). In addition to increasing water demand associated with population growth, urbanisation and economic development, climate change is exacerbating the global water shortages (United Nations Water 2026a). With only five years remaining until the 2030 deadline for the United Nations' Sustainable Development Goals (SDGs), there is an urgent need to develop

practical and cost-effective water conservation approaches (United Nations 2018; United Nations Department of Economic and Social Affairs 2025).

Hemodialysis is a water-intensive medical treatment that results in extensive water wastage (Abarkan et al. 2022; Barraclough et al. 2019; Agar 2010). The global burden of kidney failure requiring renal replacement therapy continues to rise, with an estimated 4.59 million people were living with end-stage kidney disease in 2023, of whom 3.57 million (78%) receive dialysis (Rafferty et al. 2025). Hemodialysis remains the predominant dialysis modality, accounting for approximately 89% of all dialysis treatments. The 600 million annual global hemodialysis sessions have a substantial environmental burden, particularly through their high water consumption and the generation of large volumes of reject water (RW) and wastewater (Wieliczko et al. 2020; Ben Hmida et al. 2023).

Hemodialysis requires continuous circulation of dialysis fluid to facilitate the removal of solutes from blood. A conventional four-hour hemodialysis session delivered at a dialysate flow rate (Q_d) of 500 mL/min requires approximately 120 L of ultrapure water (Solomon et al. 2024; Rydzewska-Rosołowska et al. 2024). Water consumption is, however, substantially higher due to intrinsic inefficiencies of reverse osmosis (RO) systems and the additional water required for priming, rinsing and disinfection (Agar 2010; Connor et al. 2010). As a result, an average RO-based hemodialysis system may consume up to 500 L per session, with as much as 380 L discharged as RW (Rydzewska-Rosołowska et al. 2024). The annual water requirement for hemodialysis is estimated to be approximately 78,000 L per patient, equating to an annual global consumption of around 270 billion L of water for hemodialysis (Wieliczko et al. 2020).

Traditionally, all RW generated by hemodialysis RO systems has been discarded as wastewater, with an estimated 70% of high-quality water being rejected during the production of ultrapure water (Wieliczko et al. 2020). In some hemodialysis settings, however, this RW is recovered and repurposed as greywater for non-clinical applications such as floor cleaning, toilet flushing, gardening or farming (Ponson et al. 2014; Tarrass et al. 2021; Tarrass and Benjelloun 2023). Although more efficient RO systems are available, their high-cost limits implementation in many hemodialysis facilities as these systems are large and complex, making installation and disassembly difficult (Abarkan et al. 2022; Connor et al. 2010; Ponson et al. 2014). This has important sustainability implications considering that the global dialysis population will double by 2030 to around 5 million (Wieliczko et al. 2020).

Agar et al., showed that practical conservation measures reported the recovery and reuse of > 100,000 L of reject water per week across facility and community applications (Agar et al. 2009). Furthermore, Barraclough et al. found that in Victoria, Australia, only 25% of surveyed dialysis facilities were recycling RO reject water, indicating that sustainable practices remain limited (Barraclough et al. 2019). Therefore, development and implementation of water conservation, recovery and wastewater reuse strategies should be regarded as essential components of sustainable hemodialysis practices (Ben Hmida et al. 2023).

Previous reviews have considered selected water saving strategies in hemodialysis (Molano-Triviño et al. 2017), but a current scoping review specifically focused on current water-conservation methods in clinical hemodialysis settings has not been identified. Preliminary findings from this work have previously been presented in conference abstract form, reflecting early recognition of the importance of water conservation in

hemodialysis and reinforcing the need for a more detailed synthesis of the existing literature (Sen et al. 2024).

This scoping review aims to examine and characterise the current water conservation methods utilized in clinical hemodialysis settings, including strategies to reduce water consumption, reuse RW and recycle dialysis-related effluents as well as to identify reported implementation factors, outcomes and research gaps.

Methods

Protocol development

This scoping review follows the Preferred Reporting Items for Systematic review and Meta-Analysis (PRISMA-2020) reporting guidelines (Page et al. 2021) with a prospectively developed protocol published in the Open Science Framework database (<https://doi.org/10.17605/OSF.IO/YRDNJ>). The scoping review addressed the following question: How can water intensive healthcare hemodialysis reduce potable water demand and safely implement circular water reuse practices?

Eligibility criteria

Eligibility criteria were established using the PCC (Population, Concept, Context) framework to ensure alignment with the review aim. The population included hemodialysis patients of any setting or geographic location worldwide. The concept was defined as water conservation methods in hemodialysis tertiary facilities. The context encompassed inpatient and outpatient hospital settings. Studies were excluded if they did not align with the PCC framework, discussed water use or the environmental impact of hemodialysis without addressing water conservation methods, were opinion pieces, commentaries, editorials, letters, perspectives, protocols, abstracts or conference presentations or were not available in English. No date limit was applied.

Search strategy

Six authors (AS, KB, NM, TT, AG and MO) developed the search strategy to align with the review question and eligibility criteria. A combination of a MeSH term ('Wastewater') and free-text title/abstract terms were combine using Boolean operators to systematically search PubMed, EMBASE, Web of Science, CINAHL and Scopus for studies published from inception to 7 March 2026. Preliminary searchers were first conducted in PubMed and EMBASE and subsequently translated for use in Web of Science, CINAHL and Scopus utilising Polyglot, accessed via the Evidence Review Accelerator (TERA). (Clark et al. 2020) While the search syntax was translated across databases using Polyglot, the mapping of controlled vocabulary terms was checked and adapted manually. In addition, the reference lists of relevant systematic reviews were hand-searched to identify any further eligible studies.

Screening and selection process

Identified articles were independently screened by title and abstract against the eligibility criteria within Covidence. Following retrieval of the full-text articles, authors screened each full text for inclusion. Discrepancies were resolved by consensus.

Data charting process

Data were charted using a customised extraction template to ensure consistent capture of study characteristics, intervention details and water related outcomes relevant to the review question. The draft data extraction template was reviewed, piloted and refined prior to data extraction of included articles being undertaken. As the included studies clustered into two main categories, the extraction template was organised separately for dialysate flow rate modification and reverse osmosis reject water reuse studies. This allowed study characteristics and outcome data to be charted consistently according to intervention type, whilst maintaining a common framework across all included studies. Extracted variables included author and year, study design, setting, intervention characteristics, and quantitative water-related outcomes relevant to each category.

Synthesis of dialysate flow rate modification and reject water studies

Given the heterogeneity in intervention types, outcome definitions and reporting units across included studies, a descriptive quantitative synthesis was undertaken. For dialysate flow rate modification studies, extracted outcomes included dialysate or water use per hemodialysis session, water or dialysate saved per session and total reported savings over the study period (Table 1). Only facility-based hemodialysis data were included to support comparability across studies. Where studies reported both dialysate and purified water volumes, these were recorded separately and were not combined. For studies evaluating reverse osmosis reject water generation and reuse, extracted outcomes included total water use per session, reject water volume generated and reject water volume reused or saved (Table 2). When reject water reuse was reported only over daily or weekly periods, annual estimates were calculated using 365-day or 52-week standardisation and were clearly identified as inferred values. For consistency, “treatment” and “session” were treated as equivalent hemodialysis units where different terminology was used by study authors. Results were therefore synthesised narratively and presented in tabular format.

Results

Study selection

The study selection process is summarised in the PRISMA flow diagram presented in Fig. 1. The systematic search identified 1228 records, of which 639 duplicates were removed. The remaining records were screened by title and abstract, after which 530 were excluded. This resulted in 59 articles being assessed in full text against the eligibility criteria. Of these, 45 were excluded with almost perfect agreement (Cohen’s kappa = 0.932) (Landis and Koch 1977), leaving 14 studies included in the final review (Fig. 1). One study reported only theoretical water savings without providing extractable quantitative data (Coritsidis et al. 2025).

Characteristics of included studies

The key characteristics of included studies are described in Fig. 2. The 14 articles derived from the systematic search represented findings from 12 countries (Fig. 2a), with two studies emanating from the United States (Coritsidis et al. 2025; Parikh et al. 2025) and Morocco (Alayoud et al. 2012; Tarrass et al. 2025) (Fig. 2b). Nine studies focused on dialysate flow rate modification as water conservation strategies (Solomon et al. 2024; Rydzewska-Rosołowska et al. 2024; Coritsidis et al. 2025; Parikh et al. 2025; Alayoud et al. 2012; Albalate et al. 2015; Aktaş et al. 2023; David et al. 2025; Ramos et al. 2026) and five studies focused on RW reuse (Agar 2010; Connor et al. 2010; Ponson et al. 2014; Tarrass et al. 2025; Chang et al. 2021) (Fig. 2d). Dialysate flow rate modification studies were conducted across Spain, Türkiye, the United States, Germany, Colombia, Poland and India, and more often used prospective crossover, retrospective cohort or practice-change designs involving hemodialysis patients (Fig. 2b). Across these dialysate flow rate modification studies, sample sizes ranged from 23 to 433 participants and the water-conservation approach consisted primarily of reducing Qd to 300 mL/min (Solomon et al. 2024; Rydzewska-Rosołowska et al. 2024; Coritsidis et al. 2025; Parikh et al. 2025; Aktaş et al. 2023), implementing AutoFlow (Alayoud et al. 2012; Albalate et al. 2015; David et al. 2025), or using alternative low-flow dialysate prescriptions (Solomon et al. 2024; Parikh et al. 2025; Ramos et al. 2026) (Fig. 2d). Reject-water studies (Agar 2010; Connor et al. 2010; Ponson et al. 2014; Tarrass et al. 2025; Chang et al. 2021) were predominantly facility-level implementation or feasibility reports from the United Kingdom, Australia, Malaysia, France and Morocco, and evaluated infrastructure or reuse pathways rather than clinical outcomes (Fig. 2b).

Dialysate flow rate modification studies

Nine studies investigating dialysate flow modification strategies in clinical hemodialysis were included (Table 1). Eight of nine studies reported quantitative data on dialysate flow or water use at the sessional level (Solomon et al. 2024; Rydzewska-Rosołowska et al. 2024; Parikh et al. 2025; Alayoud et al. 2012; Albalate et al. 2015; Aktaş et al. 2023; David et al. 2025; Ramos et al. 2026) while one study provided only theoretical estimates (Coritsidis et al. 2025). Studies were mostly conducted as patient-level clinical or observational studies, including prospective crossover studies, prospective non-randomized trials, retrospective observational studies, and *post hoc* cohort analyses. Studies published in 2012 and 2015 were mainly single-centre prospective cross-over designs (Alayoud et al. 2012; Albalate et al. 2015). Later studies (2023–2026) broadened methodologically to include multicentre observational work (Parikh et al. 2025) and practice-change analysis (David et al. 2025), as well as retrospective (Rydzewska-Rosołowska et al. 2024) and *post hoc* analysis (Ramos et al. 2026). Across studies, baseline dialysate consumption for a standard 4-hour hemodialysis session at Qd 500 mL/min ranged from approximately 120–150 L per session. Values of 120 L/session were reported by Albalate et al. (Albalate et al. 2015), Alayoud et al. (Alayoud et al. 2012), Ramos et al. (Ramos et al. 2026), and Solomon et al. (Solomon et al. 2024). Two studies reported similar baseline dialysis consumption of 127.5 L/session (David et al. 2025) and 126 L/session (Parikh et al. 2025), whereas Aktaş et al. reported an average of 150 L/session at Qd 500 mL/min (Aktaş et al. 2023).

Sessional water or dialysate savings varied depending on the intervention. The most consistent finding across hemodialysis studies was that reducing Qd from 500 to 300 mL/min resulted in savings of approximately 48 L per session, as reported in three independent studies (Solomon et al. 2024; Rydzewska-

Rosołowska et al. 2024; Aktaş et al. 2023) (Fig. 3). Lower reductions were observed when decreasing Qd from 500 to 400 mL/min, with savings of approximately 24 L per session (Albalade et al. 2015; Ramos et al. 2026). Intermediate savings were observed with individualised dialysate-flow strategies via AutoFlow, with reductions of 35.7 L per session reported in one study (David et al. 2025). The largest reduction was observed in a multi-centre comparison of green hemodialysis versus conventional systems, in which total treatment water use was reduced by 162.3 L per treatment (Parikh et al. 2025).

Where reported, total water savings varied substantially across studies, influenced by study duration, patient numbers, and reporting units. Reported totals included 13,824 L over 12 weeks, ~ 7,500 L per patient per year (Aktaş et al. 2023), 19,656 versus 44,979.5 L/year (Parikh et al. 2025), 194,688 L/year in a 26-patient unit (Rydzewska-Rosołowska et al. 2024) and 1,440 L/day purified water saved at unit level (Solomon et al. 2024). Overall, despite heterogeneity in reporting, all studies demonstrated that reducing dialysate flow rate or individualising dialysate delivery was associated with measurable reductions in dialysate or water consumption, while dialysis adequacy and small solute clearance was generally maintained.

Table 1
Water use and water savings in dialysate flow rate modification studies (n = 9).

Study	Study design	Intervention	Sessional dialysate or Water use	Water/Dialysate saved per session	Total savings reported
Albalate et al., 2015	Prospective single-centre crossover study.	Qd 400 mL/min vs. Qd 500 mL/min vs. Qd 700 mL/min	96 L (Qd400 mL/min) 120 L (Qd500 mL/min) 168 L (Qd700 mL/min)	24 L/session 48 L/session 72 L/session	7,428 L/year at (Qd 500 mL/min vs. Qd 700 mL/min); 11,232 L/year (Qd 400 mL/min vs. Qd 700 mL/min)
Alayoud et al., 2012	Prospective single-centre crossover study	Individualised Qd (AF) vs. Qd500 mL/min	96 L (AF) 120 L (Qd500 mL/min) 89L of PW (AF) 112 L of PW (Qd500 mL/min)	24 L/session 23 L PW/session	Not reported
Aktaş et al., 2023	Prospective multicentre study	Qd 300 mL/min vs. Qd 500 mL/min	102L/session (Qd 300 mL/min) 150 L/session (Qd500 mL/min)	48 L/session	~ 7,500 L/year/patient
Coritsidis et al., 2025	Prospective non-randomized trial	Qd 300 mL/min vs. ≥ 500 mL/min	Not reported	Not reported	Not reported
David et al., 2025	Observational change-of-practice study	Qd 500 mL/min vs. Individualised Qd (AF)	127.5 L/session (Qd 500 mL/min) 92 L/session (AF)	35.7 L/session	Not reported
Parikh et al., 2025	Retrospective multicentre observational study	Qd 300 mL/min (Green HD) vs. Qd 500 mL/min	126.0 L/session (Qd 300 mL/min) 288.3 L/session (Qd 500 mL/min)	162.3 L/session	19,656 vs. 44,979.5 L/year; ~25,000 L saved/person/year

Study	Study design	Intervention	Sessional dialysate or Water use	Water/Dialysate saved per session	Total savings reported
Ramos et al., 2026	Post hoc retrospective cohort analysis	Qd 400 mL/min vs. Qd 500 mL/min (HDx)	96 L/session (Qd 400 mL/min) 120 L/session (Qd 500 mL/min)	24 L/session	13,824 L over 12 weeks
Rydzewska-Rosołowska et al., 2024	Retrospective observational study	Qd 300 mL/min vs. 500 mL/min	72 L/session (Qd 300 mL/min) ≥ 120 L/session (Qd500 mL/min)	≥ 48 L/session	194,688 L/year (26-patient unit)
Solomon et al., 2024	Single-centre non-randomized open-label cross-over pilot trial	Qd 500mL/min (NTNF) vs. Qd 500mL/min (HTNF) vs. Qd 300 (HTNF)	120 L/session (NTNF / HTNF at Qd 500 mL/min). 72 L/session (HTLF at Qd 300 mL/min).	48 L/session (40% reduction)	1,440 L/day of PW saved (unit-level)

Note: HD: hemodialysis; Qd: Dialysate flow rate; HDx: Expanded hemodialysis (dialyzers with membranes capable of enhanced clearance of medium-sized molecules due to expanded pore capacity); AF: AutoFlow; PW: Purified water; NTNF: Normal-Temperature Normal-Flow (37 °C); HTNF: High-Temperature Normal-Flow (38.5 °C).

Reject water recapturing studies

Five studies reporting on reverse osmosis RW generation and reuse in clinical hemodialysis settings were included (Table 2). Reject water studies were predominately service-level implementation reports, technical case studies, or feasibility/modelling studies, with a strong focus on infrastructure, reuse pathways and operational outcomes. This is reflective of RW reuse as largely a system, engineering and implementation issues rather than a patient-level prescription issue. Four different studies by Agar et al., Connor et al., Ponson et al. and Chang et al. primarily described implementation of reuse systems and volumes of RW that be recovered or redirected (Agar 2010; Connor et al. 2010; Ponson et al. 2014; Chang et al. 2021), while Tarrass et al. extended this to a national-scale feasibility model (Tarrass et al. 2025).

Across five studies, substantial volumes of reject water were identified as available for reuse. Connor et al., reported > 250 L of reject water per session, with reuse of 14,400 L/day and 4.5 million L/year at a single facility (Connor et al. 2010). Agar et al., reported ~ 65,000 L/week of facility-based reject water reuse, corresponding to ~ 3.38 million L/year (Agar 2010). Chang et al., reported 10,000–12,000 L/day of reject

water redirected to aquaponics and horticulture systems, equating to an estimated average of ~ 4.0 million L/year (Chang et al. 2021). Ponson et al., reported 2834 m³/year of reject water, of which 1200 m³/year was considered appropriate for sanitation reuse (Ponson et al. 2014). Tarrass et al., estimated national reject water generation in Morocco at ~ 1.1 million m³/year, although this represented modelled production rather than direct implementation data (Tarrass et al. 2025). Two studies directly reported total sessional water consumption for in-centre hemodialysis, with values consistently of approximately 493–500 L per treatment. Connor et al., reported approximately 400 L/session for hemodialysis-grade water production and approximately 500 L/session when priming and rinsing were included (Connor et al. 2010), while Agar et al., reported 493 L/treatment for in-centre dialysis (Agar 2010). No other studies provided directly comparable sessional water use data. Overall, facility-level water reuse ranged from approximately 1.2–4.5 million L/year/centre, with higher values associated with large or optimized systems. Direct comparisons between studies were limited by differences in reporting units (sessional, daily, weekly, annual), reuse endpoints and whether values represented theoretical availability or actual reuse.

Table 2
Water use and water savings across reject water studies (n = 5).

Study	Study Design	Total water use (per session)	Reject water generated	Water reused or saved	Timeframe	Water reuse applications
Connor et al., 2010	Implementation case study	~ 400 L/session (HD-grade water); ~500 L/session total including priming/rinsing	> 250 L/session	14,400 L/day; 4,492,000 L/year	Daily and annual	Laundry and sanitation.
Agar et al., 2010	Service-level report	493 L/treatment (in-centre HD only)	Not reported	~ 65,000 L/week (facility-based reuse only) ~ 3.38 million L/year*	Weekly and annual	Autoclave steam generation, toilet flushing, janitor stations, garden maintenance, sporting fields, schools, aged-care gardens.
Chang et al., 2021	Implementation report	Not reported per session	10,000–12,000 L/day (reject water)	10,000–12,000 L/day reused (assumed full reuse in system) ~ 3.65–4.38 million L/year*	Daily and annual	Aquaponics, hydroponics and horticulture
Ponson et al., 2014	Technical economic case study	Not reported per session; total 9286.78 m ³ /year processed	2834 m ³ /year reject water	1200 m ³ /year reused (feasible sanitation reuse)	Annual	Building sanitation, particularly toilets.
Tarrass et al., 2025	Feasibility and modelling study	Not reported per session	~ 1.1 million m ³ /year (national estimate)	Not directly reported (modelled agricultural reuse)	Annual	Agricultural irrigation, specifically potato farming.

*Inferred values derived from reported daily or weekly values using standard calendar conversions.

Discussion

This review demonstrates that water conservation in dialysis is achievable and necessary, showing that meaningful improvements can be achieved in two main ways: Dialysate flow rate modification and re-purposing of reverse osmosis RW.

In the dialysate flow rate modification literature, several studies showed that lowering dialysate flow can reduce water or dialysate consumption without clinically significant short-term compromise in adequacy. Albalade et al., found that increasing Qd above 400 mL/min provided only limited gains in dialysis adequacy, while substantially increasing dialysate consumption, and concluded that extending dialysis time was a more efficient trade-off than using higher water volumes (Albalade et al. 2015). Similarly, Solomon et al. reported that reducing Qd from 500 to 300 mL/min lowered purified water use by 40% without compromising adequacy or short-term safety in young, haemodynamically stable patients (Solomon et al. 2024).

AutoFlow or automatic dialysate adjustment, represents a particularly attractive dialysate conservative strategy as it individualizes dialysate flow to blood flow and can reduce dialysate use without clear short-term compromise in adequacy. In the present review, AutoFlow was shown to reduce dialysate use from 120 to 96 L/session (Alayoud et al. 2012) and 127.5 to 92 L/session (David et al. 2025), which corresponds with a dialysate saving of 24 L/session and 35.7 L/session, respectively. An additional, yet to be determined, opportunity may be to combine AutoFlow with intradialytic cycling as exercise during hemodialysis has been proposed to enhance uraemic toxin clearance, stabilises vascular resistance, improve blood pressure stability and treatment tolerance without increasing symptomatic intradialytic hypotension and other adverse events (Kirkman et al. 2019; Rossum et al. 2023; Khamis et al. 2025). Therefore, it is plausible that AutoFlow combined with intradialytic cycling exercise could be an effective tool in selected patients, potentially preserving adequacy and prevent physical decline while maximising dialysate and water savings.

In parallel, reject-water studies illustrated that large volumes of otherwise wasted water can be redirected into useful secondary applications. Implementation of Reject-water recapturing technology appears feasible across a range of healthcare settings, but its economic viability is likely to depend on local infrastructure, intended reuse pathway and institutional budget. In the current scoping review, the best evidence for financially viable fixed-site recapture systems came from high-income countries, including the United Kingdom, Australia and France, where reject-water reuse was integrated into hospital or dialysis unit infrastructure for laundry, sanitation, sterilization, and community irrigation. A case study from a renal dialysis centre in Canterbury, UK by Connor et al. reported 4.49 million L/year of recovered RW with a net annual financial savings of > £10,000/year (Connor et al. 2010), while Ponson et al. estimated that sanitation reuse of 1200 m³/year could achieve a 5.8-year return on investment (Ponson et al. 2014). In contrast, studies from upper-middle-income countries such as Malaysia, Morocco, Colombia and Türkiye, and from the lower-middle-income setting of India, suggest that lower cost or context-adapted conservation strategies including reuse in aquaponics, horticulture, agriculture or water-saving dialysis prescriptions that reduce dialysate demand may be more cost effective and realistic than overhauling the infrastructure. These findings suggest that RW recapture technology is transferable, but cost may vary based on facility setting. To this end, high income countries may be better positioned to build recapture and redistribution systems, while middle-low-income settings may derive immediate benefit from simpler, cheaper reuse applications and dialysate flow reduction strategies.

The practical and safety considerations differ between the two water sustainability approaches. Across the dialysate flow rate modification studies, there was little evidence of patient harm associated with reducing or individualizing dialysate flow although some important cautions emerged. Rydzewska-Rosołowska et al. found that by reducing Qd from 500 to 300 mL/min did not significantly worsen urea reduction ratio or the dialysis adequacy but was associated with a small yet statistically significant increase in mean pre-dialysis potassium, suggesting that lower-flow prescriptions may warrant caution in patients already prone to hyperkalaemia (Rydzewska-Rosołowska et al. 2024). Solomon et al. similarly reported preserved adequacy with their high temperature, low-flow prescription, but observed one episode of symptomatic hypotension requiring dialysis termination. Notably, this intervention altered both dialysate flow and temperature, so the event cannot be attributed to low flow alone (Solomon et al. 2024). Coritsidis et al., also suggested that longer exposure to Qd 300 may be associated with a rise in serum potassium in few patients but had stable short-term metabolic outcomes (Coritsidis et al. 2025). Overall, these findings suggest that dialysate-flow reduction appears broadly safe in selected populations such as individuals with good vascular access, not high blood flow rates and less tendency to gain fluid weight but should not be viewed as risk-free (Agar 2010). The reported concerns were more consistent with potentially undesirable events such as biochemical or haemodynamic changes than with clear evidence of patient harm. As these changes may be identified and managed before harm occurs, careful patient selection, monitoring of biochemical parameters, particularly potassium and attention to haemodynamic vulnerability remain important when implementing lower flow dialysis strategies. In this regard, most studies reported that lower dialysate flow rates maintained dialysis adequacy without clear adverse clinical consequences of waste metabolite accumulation or on quality of life, supporting the feasibility of water-sparing prescriptions in selected patients (Solomon et al. 2024; Rydzewska-Rosołowska et al. 2024; Parikh et al. 2025; Albalade et al. 2015; Aktaş et al. 2023; David et al. 2025; Ramos et al. 2026).

In contrast, the main challenge with RW reuse is less about immediate patient adequacy and instead demonstrating that the water is chemically and biologically suitable for secondary use. Across the reject-water studies, reuse was generally complimented by water quality assessment, although the rigor and scope of testing varied. Agar et al., provided the strongest quality assessment through repeated water testing to demonstrating that RO reject water was essentially comparable with local potable water, apart from minor conductivity differences within accepted limits for reuse (Agar 2010). Chang et al. similarly performed pre-implementation water testing and reported parameters suitable for aquaculture, supporting reuse in aquaponics, hydroponics, and horticulture (Chang et al. 2021). Ponson et al. used physicochemical testing, including sodium measurement, to justify restricting reuse to sanitation applications rather than broader reuse pathways (Ponson et al. 2014). Tarrass et al. concluded that reject water met irrigation-water standards for agricultural reuse (Tarrass et al. 2025), while Connor et al. described reject water as high-grade grey water that commonly met potable criteria (Connor et al. 2010), *albeit* with the implication that local verification remained necessary before implementation.

In Australia, reuse of reject water is especially relevant because recycled water is managed under the Australian Guidelines for Water Recycling (AGWR), which use a fit-for-purpose, risk-based framework requiring hazard identification, risk assessment, treatment validation, and ongoing monitoring according to the intended end use (Natural Resource Management Ministerial Council et al. 2006). Reject water reuse should be tailored to the proposed application, such as irrigation, sanitation, horticulture and therefore may

need to include not only microbiological indicators such as *E. coli* or thermotolerant coliform testing, but checking chemical and salinity parameters, such as electrical conductivity, total dissolved solids, sodium, chloride, and boron, particularly when there is risk of soil degradation, plant toxicity, or groundwater impact (Department of Environment and Conservation 2004).

An additional, largely unexplored consideration in these studies is whether plastic components associated with dialysis water treatment and delivery systems may shed micro- or nanoplastics into the water pathway. While this was not evaluated in the included studies, emerging reviews show that MNPs can accumulate in respiratory (Goldsworthy et al. 2025a), cardiovascular (Goldsworthy et al. 2025b), and urinary systems (O'Callaghan et al. 2025) and cause harmful cellular effects. Emerging evidence highlights the dangers of both plastic particles and chemicals within plasticized medical devices used in dialysis like plastic tubing, dialysate bags and roller pumps and (Green et al. 2025; Saunier and Yagoubi 2021; Briceño and Runge 1992). Recent studies demonstrate the potential for nanoplastic particles to be up taken by harm to crops such as wheat and tomatoes, if RW is repurposed in agriculture (Ziajahromi et al. 2026). Additionally, the use of RW in irrigation, may aerosolize harmful particles presenting a threat to human and animal respiratory health. Accordingly, future studies of both reject-water reuse and dialysate-conservation strategies should consider MNP monitoring as part of water-quality assessment.

A notable finding of this review was the disconnect between the volume of discussion surrounding sustainable dialysis and the relatively small number of studies demonstrating practically implemented water conservation strategies. In addition to the included studies, a substantial number of excluded records comprised of abstracts (n = 19), conference papers (n = 3) and perspective pieces (n = 2), (Table 1), indicating that the issue is widely recognised but less frequently translated into evaluated service-level initiatives. From a COM-B Theoretical Domains Framework (TDF) perspective (Michie et al. 2011; Cane et al. 2012), this gap likely reflects barriers in capability, opportunity and motivation. Services may lack the technical knowledge and skills required to operationalise the change such as infrastructure limitations, cost and regulatory complexity and remain hesitant in the absence of strong safety, economic and long-term effectiveness data (Yasar et al. 2025; Piccoli et al. 2025). These findings suggest that advancing water conservation in hemodialysis will require implementation science approaches that address behavioural, organisation and system-level barriers, rather than relying on awareness alone.

Potential barriers to implementation were considered using the COM-B model and mapped to relevant TDF domains to illustrate why promising water-conservation strategies may remain under-implemented despite increasing awareness (Table 3).

Table 3

Potential implementation barriers to dialysate flow rate modification and reject water reuse strategies in hemodialysis, interpreted using the COM-B model and TDF.

COM-B domain	TDF domain	Barriers	Facilitators
Capability	Knowledge	Lack of expertise in plumbing, water-treatment systems, recycled-water governance and hospital building/modification requirements. Limited awareness of how water-saving strategies can be implemented safely in clinical dialysis settings.	Increased collaboration between key stakeholders including clinicians, administrators, engineers, architects, infection-control teams, facilities staff and tradespeople. Development of practical guidance documents and implementation case studies.
	Skills	Limited technical skills to modify dialysis prescriptions, integrate reuse systems, interpret recycled-water requirements, or manage upgraded infrastructure.	Staff training in water-saving dialysis prescriptions, infrastructure operation and water quality management. Access to technical support.
	Memory, attention, and decision processes	Sustainability initiatives may be overlooked in routine dialysis environments where immediate clinical issues are propriety. Difficulty integrating water conservation into routine decision making.	Use of checklists, protocols and decision support tools (AI) to embed sustainability into routine care and infrastructure planning.
	Behavioural regulation	Lack of standardised protocols for implementing reduced Qd prescriptions of reject-water reuse pathways. Variable monitoring and follow-up practices.	Development of local protocols, audit cycles, implementation pathways and clear frameworks for patient safety and water quality assurance.
Opportunity	Environmental context and resources	Legacy/heritage infrastructure, plumbing/retrofitting challenges, limited space, equipment complexity, cost of installation and maintenance, lack of access to reuse pathways.	Fit-for-purpose planning, phased implementation, dedicated capital support, integration into new builds/refurbishments and use of established recycled water frameworks such as AGWR.
	Social influences	Sustainability not yet embedded in renal service culture, limited leadership support, competing clinical priorities, uncertainty surrounding who is responsible for implementation	Strong leadership support, shared ownership across clinical and non-clinical teams, institutional culture that values environmental stewardship alongside patient care.
Motivation	Beliefs about capabilities	Concerns about dialysis adequacy (potassium, hypotension or water quality). Uncertainty about economic	Demonstration studies showing maintained adequacy, manageable safety signals and practical reuse outcomes.

COM-B domain	TDF domain	Barriers	Facilitators
		return. Limited confidence in feasibility, sustainability seen as secondary to clinical delivery.	Sharing of successful implementation examples to build confidence.
	Social or professional role identity	Perception that water conservation is not a core responsibility of renal clinicals of dialysis services. Sustainability may be viewed as outside the traditional scope of care.	Framing water conservation was part of high-quality, responsible healthcare and aligning it with professional values, environmental stewardship and healthcare sustainability.
	Beliefs about consequences	Concerns regarding patient safety, regulatory risk, infection risk, environmental contamination or unintended harm. Fear that modifications may compromise care of generate liability.	Clear evidence that lower dialysate flow can maintain adequacy in selected patients and that reject-water reuse can be safely managed when aligned with fit-for-purpose water quality assessment and governance.
	Emotions	Resistance to changing established dialysis routines, burnout due to high work demands and anxiety about introducing unfamiliar sustainability practices. Limited incentives or reinforcement for adopting change.	Leadership endorsement, viable institutional support, recognition of sustainability efforts and framing change as achievable rather than burdensome.
	Goals	Sustainability goals may be poorly defined or not prioritised relative to service throughput, staffing and immediate clinical outcomes.	Inclusion of water conservation targets in departmental quality improvement plan, sustainability strategies and renal service performance indicators.
	Intentions	General support for sustainability may not translate into definitive implementation plans or timelines.	Action oriented planning with defined responsibilities, staged implementation and measurable targets for water savings and reuse.
	Reinforcement	Limited feedback, incentives or recognition for services that adopt water conservation strategies.	Reporting water savings, cost savings and environmental gains back to staff and leadership to reinforce behaviour change.
	Optimism/pessimism	Scepticism that meaningful savings can be achieved or that system-level change is realistic in complex healthcare settings.	Use of local pilot projects and real-world case studies to show that implementation is feasible and can generate measurable benefit.

Authors comments/recommendations

To complement the systematic synthesis presented in this review, Table 4 summaries the key characteristics, findings and implementation considerations of the included studies.

Table 4

Summary of water conservation strategies reported outcomes and implementation considerations.

<p>What’s known till date on this topic</p> <p>Hemodialysis is a water-intensive therapy with a significant environmental footprint. Water conservation efforts have focused on reducing dialysate flow rate and reusing reverse osmosis reject water, but evidence remains fragmented across clinical services and feasibility studie</p>
<p>What does our study add</p> <p>This scoping review integrates evidence on dialysate flow modification and reject water reuse, showing that both can reduce water consumption in hemodialysis. It also highlights differences in safety, implementation, and governance, and reveals a gap between interest in sustainable dialysis and evidence from real-world implementation and evaluation.</p>
<p>Future recommendations on this topic</p> <p>Future research should focus on the implementation, scalability, and long-term impact of water conservation strategies. Priorities include standardized water-use reporting, clinical and operational evaluations, and robust economic analyses across healthcare settings. Reject water reuse studies should align with fit-for-purpose governance frameworks and address emerging contaminants such as microplastics. Implementation science may help overcome behavioural, organisational, and infrastructure barriers to wider adoption in hemodialysis.</p>

Conclusions

Water conservation in hemodialysis is feasible and is increasingly necessary. This scoping review identified two main methods to improve sustainability in current dialysis practice: Reducing dialysate-related water consumption and repurposing reverse osmosis reject water for secondary use. Together, the 14 included studies highlight that meaningful reductions in water use can be achieved without major short-term compromise in dialysis adequacy, whilst demonstrating that reject water can be redirected to a range of practical applications when supported by appropriate quality assessment. The main limitations of this study include the single-centre designs, heterogenous outcome measures and lack of long-term clinical, environmental and economic evaluation. Further research is needed to standardize reporting, define the most effective and context-appropriate implementation strategies, examine long-term patient, environmental safety and update water-quality frameworks for reject-water reuse to include microplastic contamination. It is now time for hemodialysis services to move beyond recognising the problem of water waste and begin implementing practical, evidence-based strategies to reduce the water footprint and create more environmentally safe and sustainable renal care facilities.

Declarations

Disclosure Statement_

The authors declare no conflicts of interest. _

Data Sharing Statement

No new datasets were generated or analysed in this study. All data included in this scoping review were derived from published studies and are available from the corresponding articles.

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Author Contributions

Arnie Sen and Kiren Bhatia initially developed the search strategy with guidance from Neelam Maheshwari, Michelle McLean and Thomas Titus. The review was updated and rerun in 2026. All authors contributed to the conception, refinement, interpretation and preparation of the current manuscript and all authors approved the final version.

Artificial Intelligence Statement

Generative artificial intelligence tools were used in a limited capacity to support the visual design and editing of selected figures and infographics. All scientific content, data, labels, and interpretations were provided, checked, and approved by the authors, who retain full responsibility for the accuracy and integrity of the final manuscript and figures.

CRedit Author Contributions Statement

Arnie Sen and Kiren Bhatia: conceptualization, methodology, investigation and development of the original search strategy. Neelam Maheshwari, Michelle McLean, and Thomas Titus: supervision, methodology, and project guidance. Matthew Olsen and Adrian Goldsworthy: methodology, investigation, data curation, formal analysis, visualization and writing original draft. Loai Albarqouni: supervision, methodology and critical review of the study design. All authors contributed to writing, review and editing, interpretation of the findings and approval of the final manuscript.

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Figures

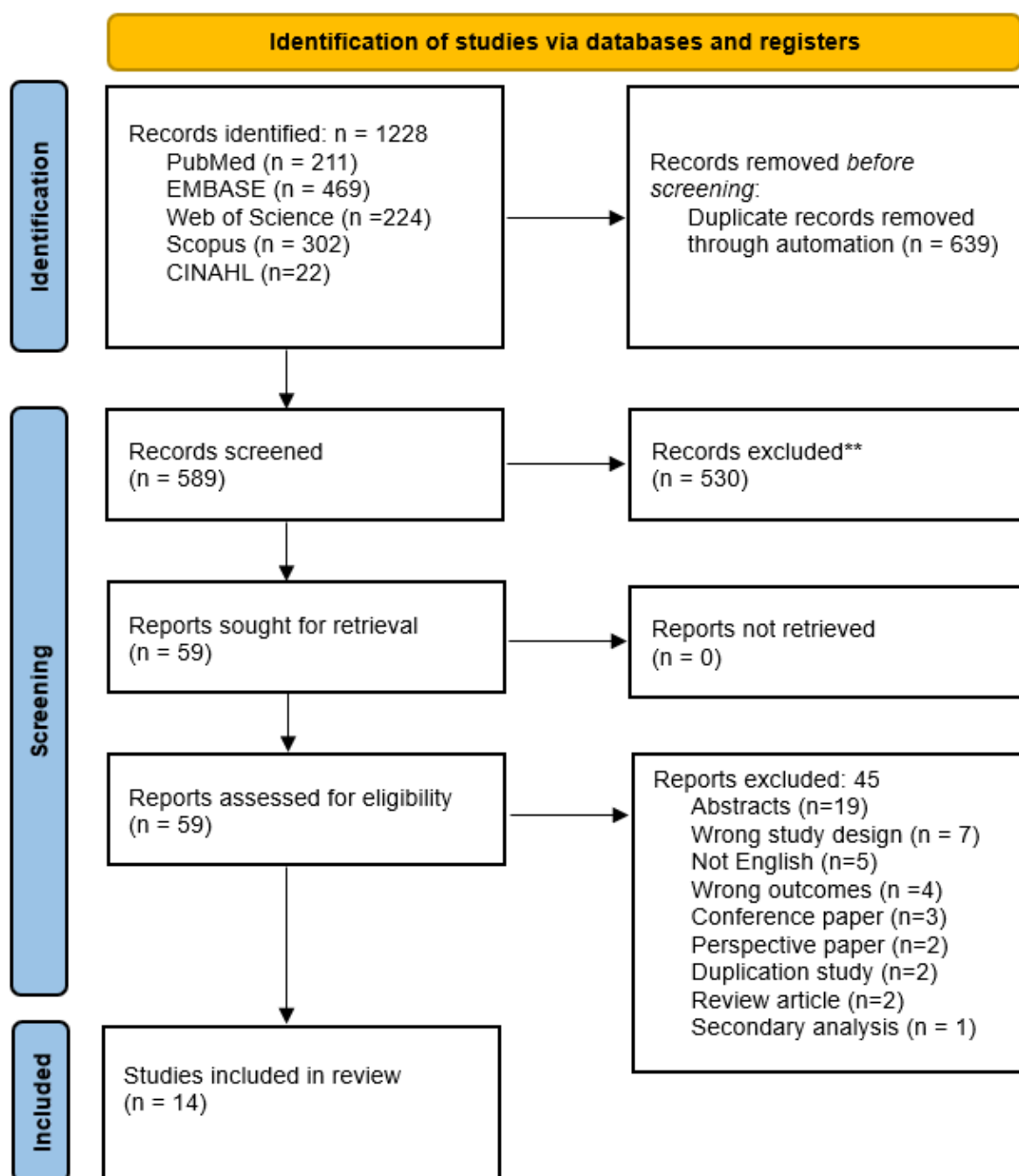


Figure 1

PRISMA flow diagram for study selection process.

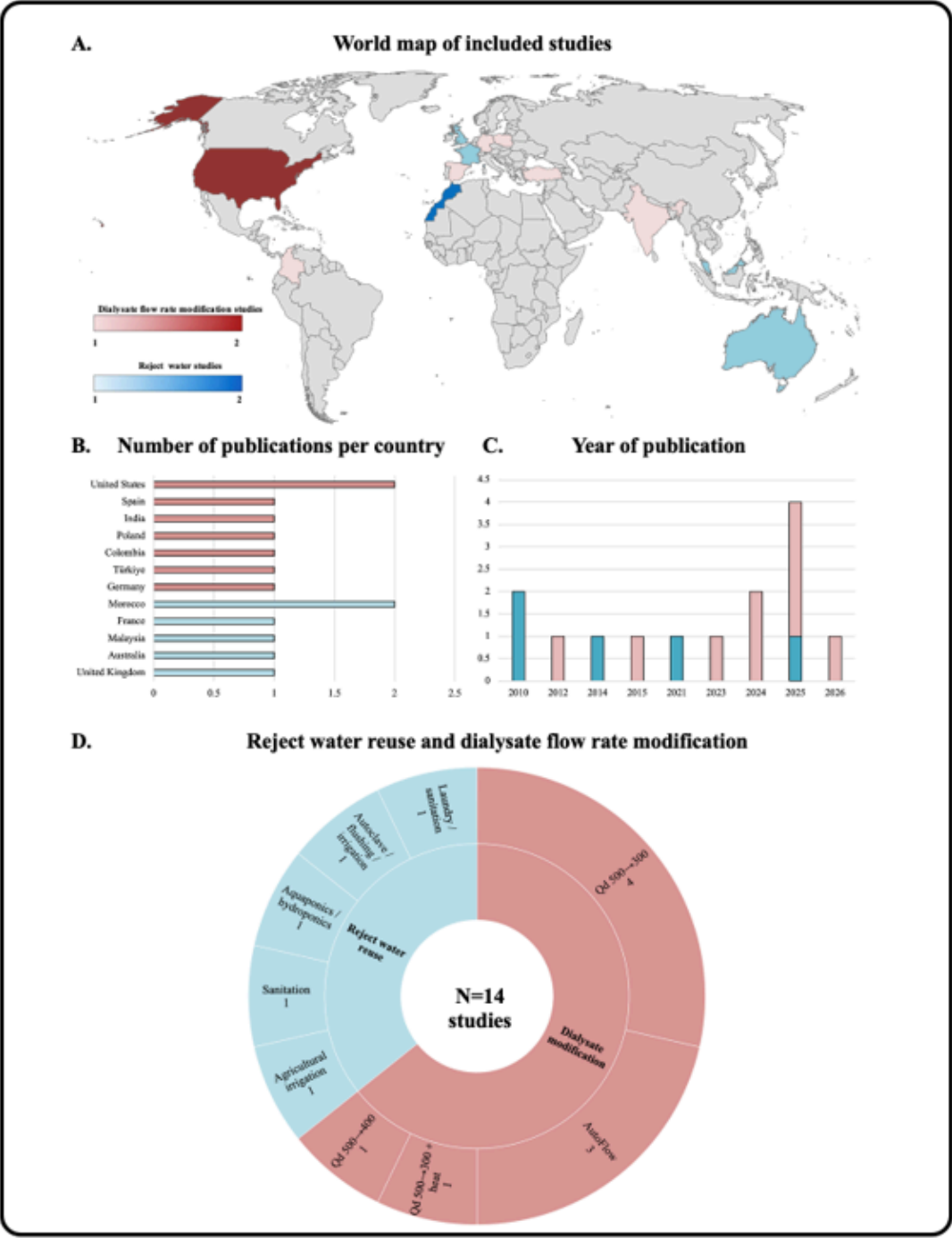


Figure 2

Key characteristics of included studies.

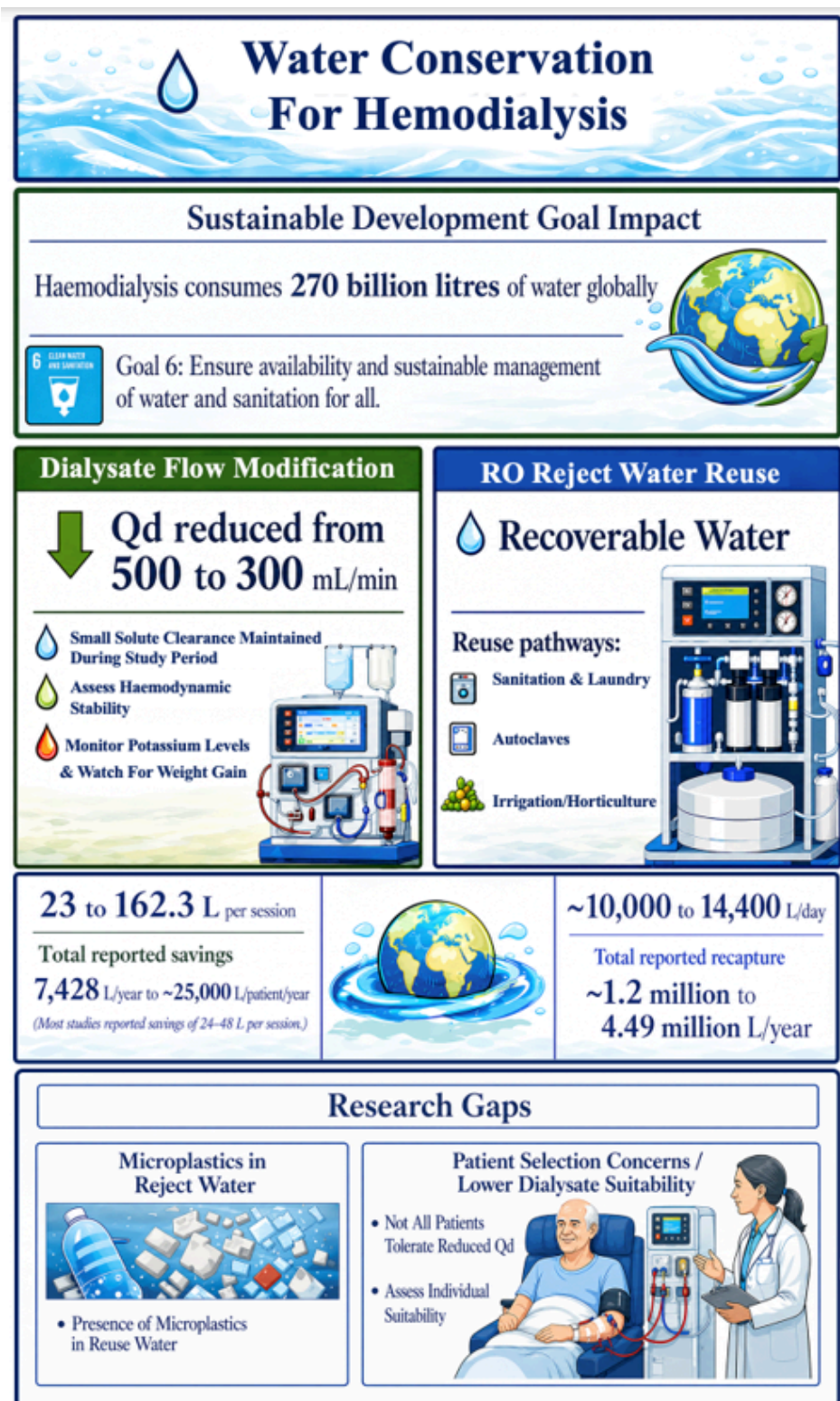


Figure 3

Overview of water conservation strategies identified in hemodialysis. The infographic summarises the two principal approaches reported in the included studies: reducing dialysate-related water use through dialysate flow rate modification and repurposing reverse osmosis RW for secondary applications.

Supplementary Files

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- [Appendix1.docx](#)