A perspective on cost-effectiveness of greenhouse gas reduction solutions in water distribution systems

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Abstract

Water distribution systems (WDSs) face great challenges as aging infrastructures require significant investments in rehabilitation, replacement, and expansion. Reducing environmental impacts as WDSs develop is essential for utility managers and policy makers. This study quantifies the existing greenhouse gas (GHG) footprint of common WDS elements using life-cycle assessment (LCA) while identifying the greatest opportunities for emission reduction. This study addresses oversights of the related literature, which fails to capture several WDS elements and to provide detailed life-cycle inventories. The life-cycle inventory results for a US case study utility reveal that 81% of GHGs are from pumping energy, where a large portion of these emissions are a result of distribution leaks, which account for 270 billion l of water losses daily in the United States. Pipe replacement scheduling is analyzed from an environmental perspective where, through incorporating leak impacts, a tool reveals that optimal replacement is no more than 20 years, which is in contrast to the US average of 200 years. Carbon abatement costs (CACs) are calculated for different leak reduction scenarios for the case utility that range from $130 to $35 t CO_2(eq).

Keywords: water distribution systems, leak management, greenhouse gases, life-cycle assessment, carbon abatement costs

1. Introduction

Water distribution systems (WDSs) face increasing challenges as population growth strains a limited water supply in many areas. These infrastructure systems, which account for the supply and treatment of drinking water from source to final consumption, must be expanded or changed to meet the growing demand. It is estimated that 25–30% of water is lost in distribution in WDSs, costing $14 billion annually [1]. In the United States, drinking water demand continues to increase while the aging of the existing supply infrastructure requires substantial attention. In 2009 the US EPA projected a needed investment of $335 billion over 20 years to US drinking water systems [2]. The American Society of Civil Engineers (ASCE)
gave these drinking water systems a grade of D, where 270 billion l (71 billion gallons) of water are lost daily in leaks in the United States [3, 4].

Most in need of these infrastructure investments are the arid regions of the United States where several states face extreme water scarcity problems [5]. One of these states, Texas, is currently experiencing one of the worst droughts in its history. At the end of 2011, 67% of the state was in 'extreme' or exceptional drought, and agricultural production losses had cost the state's industry $5.2 billion [6]. Utilizing new water resources to match demand will require increased monetary, material, and energy inputs.

Water-related infrastructure systems are major consumers of energy. One report estimates that water and wastewater services consume 3% of US electricity consumption and 7% of global energy consumption, with total global water and wastewater infrastructure energy consumption expected to grow by 33% over the next 20 years [7]. Another report estimates all water-related energy use as 13% of the total US electricity demand [8]. The California State Water Project is the greatest consumer of energy in the state, utilizing 2–3% of the state’s total electricity in moving water from northern sources to southern users [9]. These energy burdens will result in many environmental impacts, such as water use, harmful air emissions, and resource depletion. This study focuses on the greenhouse gas (GHG) implications of drinking water systems which must be quantified accurately and communicated properly to achieve holistic and strategic planning decision-making before major investments to upgrade infrastructure systems are committed to a final course of action.

Taking a life-cycle perspective on existing assets can facilitate more robust, strategic and systems-level approaches in designing future expansion projects. Identifying inefficiencies, such as distribution leaks, in current operations can reduce the energy burdens, economic costs, and GHG impacts of WDSs. This study addresses these problems by modeling GHG emissions in US WDSs, and detailing the opportunity for emission reduction through leak reduction by pipe replacement.

Leaks have become a growing concern for WDSs. The Philadelphia water department experiences 31% losses in distribution, and the Cleveland Division of Water loses 29% [10]. Other US regions with water scarcity concerns have lower losses. California’s East Bay Municipal Utility District (EBMUD) has 7% losses in distribution [11], and California averages 10% for all utilities [12]. Texas averages 13% losses in municipalities [13]. High losses extend beyond the United States, where a recent study cited 32% losses in a system in Norway [14]. China has recently emphasized a need to control leaks [15]. Water losses in distribution are now being viewed as a major indicator of a city’s environmental focus [16]. Controlling leakage also helps to maintain adequate water pressure in avoiding water contamination from intrusion events [17].

2. Related literature perspective

The existing related literature presents environmental assessments of WDSs with varying scopes, regions, and methods. Some studies utilize life-cycle assessment (LCA), while others are limited to only the operation phase for theoretical design optimization problems. Table 1 summarizes the findings of the existing literature.

The existing literature in environmental assessment of WDSs does not provide a comprehensive, detailed picture of the total impacts of a drinking water utility. Certain elements, such as water storage, are based on very general data, or are omitted entirely [25]. Assessment methods are limited, and the same data sources are reused in the literature [23, 26, 28, 29]. Distribution losses from leaks have only been loosely explored, and current work does not provide context for how they can dynamically contribute to a utility’s environmental footprint [20, 30]. Other environmental assessment studies of WDSs are focused on theoretical design problems and are not geared to aid utility decision makers in reducing their footprint [23–25, 28, 29, 31–33]. These oversights of the current body of literature have left the WDSs without proper knowledge to both quantify and reduce GHG emissions.

Existing environmental assessments of WDSs vary significantly in results. This is due to differences in methodology, scope, and geographical considerations. Pumping energy outputs, which is included in some capacity in most existing studies, ranged from 24% to 98% of total GHG emissions [25, 19]. Water treatment was another WDS aspect common to most related literature, where based on the water source energy consumption could range from 1.5 to 10% of the WDS’s total energy consumption [34, 35]. Other infrastructure aspects, where existing research has been limited, has ranged from 2 to 5% of total utility GHG emissions [25].

3. Approach to GHG reduction in WDSs

This study addresses the existing gaps in the knowledge by performing the most comprehensive WDS LCA to date while identifying the cost-effectiveness of opportunities for substantial GHG reduction in WDSs. Attempting to develop a specific model for all WDSs ignores the reality that utilities vary significantly based on geographic, social, and economic characteristics. Still, aspects of WDSs that present opportunities for significant GHG savings can be identified using the best available data. This study creates a comprehensive model that determines the cost-effectiveness of GHG reduction opportunities in WDSs and illustrates these concepts using a case study utility. Leak management is highlighted as a reduction opportunity in the case study analysis, and is applied to two regions in the United States where water scarcity is a concern.

3.1. Life-cycle inventory of case study utility

The case study utility supplies almost 37.8 GI (10 billion gal) annually to over 23 000 service connections. The case study utility, located in a western state of the United States, sits in a valley above a pristine aquifer, where the water is pumped to storage tanks in the surrounding hills to create a gravity fed system. As a result of annexing smaller WDSs over time, the utility has no dedicated transmission pipe mains. This has created a system where 40% of the water destined for customers is lost in distribution primarily to structural leaks in pipes. Although this level of losses and certain design
there are many aspects common to WDSs that are assessed in this study such as pipe materials, wells, water storage, pipe construction, and distribution leaks.

This study uses LCA to quantify a case study utility’s GHG footprint. LCA is widely used as a holistic approach to assessing products and processes through the analysis of all life-cycle stages [36], including supply-chain elements.
that might be otherwise overlooked. Materials production incorporates all upstream supply-chain entities to the point of construction. This includes geographical considerations such as electricity mixes and shipping distances. Construction is composed of all GHG emissions related to the assembly and installation of WDS infrastructure elements. This includes on-site equipment use and temporary materials. Operation and maintenance encompasses all GHG emissions that result from inputs related to the delivery of drinking water to customers after construction is completed. Some materials or inputs are continually used in this phase, such as treatment chemicals, electricity for pumping, and repair/replacement of pipelines.

The life-cycle emissions of four engineered WDS assets were assessed: water wells, water storage, booster pumps, and pipelines. Pumping energy inputs were quantified at water wells and booster pumps, and treatment inputs were quantified at water wells. Water-well material quantities were taken from sample as-built drawings, and depths were customized to the specific designs of the case utility. The utility supplied as-built water storage facilities for material quantities. Booster pump material quantities were estimated from site visits and data provided by the utility. Pipeline materials were taken from the utility’s record of pipe inventory. Construction and maintenance practices were quantified from the utility’s feedback and existing literature.

After determining the construction and material inputs from case study utility data, the GHG impacts were calculated for each specific asset. Specific methods and data sources can be found in the supplementary data (available at stacks.iop.org/ERL/9/024017/mmedia).

4. Life-cycle inventory results

The LCI results are disaggregated into 8 different WDS elements. Results were tracked through each life-cycle phase and element of the WDS on a per-gallon basis, and scaled up based on the utility’s annual water volume delivered to customers. A gallon delivered to customers, including losses in distribution, was chosen as the functional unit for relevance to the case utility and US WDSs. The GHG footprint for the case utility is calculated over a 50-year analysis period based on the case utility’s interest in this length of time. Demand was assumed to be fixed for this time period. Pumping energy, treatment, and maintenance accrued annually over the analysis period. Pipes, tanks/reservoirs, wells, booster pumps, and pipe construction only occur once and are distributed evenly over the analysis period.

Pumping energy makes up the majority (81%, 10 000 ton CO\(_2\)eq annually) of the total GHG footprint. The pumping energy may be higher than in other utilities because of the substantial leaks in distribution, and could drastically be reduced by controlling leaks.

Since the utility studied is using a very clean water source by comparison to many other utilities, the treatment impacts are minimal with emissions 10 times less than, e.g., imported freshwater in Southern California [21]. Other water sources, such as desalinated or recycled water, will require more treatment inputs where GHG emissions are 5–7.5 g CO\(_2\)/gal and 0.5 g CO\(_2\)/gal, respectively.

Piping materials accounted for the second largest contributor to emissions (6%, 700 t CO\(_2\)eq annually). The case study utility has over 480 km (300 miles) of pipes. Six pipe material types were studied based on the utility’s inventory: cast iron, concrete-lined ductile iron (DICL), polyethylene (PE), concrete asbestos, PVC, and steel. DICL and PVC are the choice materials of the case utility in recent decades, whereas steel, cast iron, and concrete asbestos represent aging stock that may need replacement.

Pipe maintenance activities account for 5% (550 t CO\(_2\)eq annually) of the total emissions. Asphalt emissions could be significantly reduced by using HDD construction methods. Operation fuel usage composes 4% (520 t CO\(_2\)eq annually) of emissions, where the case utility would find savings if vehicle and generator efficiencies were upgraded. Currently, all vehicles are internal combustion engine only.

Pipeline construction emissions (2% of total emissions, 220 t CO\(_2\)eq annually) include only equipment and material inputs in initial construction of pipelines, which does not
include the pipes and does not accrue annually. The initial construction of the entire case study utility’s network was performed using open-trench techniques.

Tank materials include all water storage facilities’ GHG emissions. These facilities represent a small portion of the total utility emissions (1%, 90 t CO$_{2}$eq annually). Although only minimally contributing to GHGs, the water storage analysis represents the most detailed LCA of this WDS aspect for the research field. These storage facilities assessed in this research do not represent the only common design used by US WDSs. Other designs, such as spheroidal tanks, are often used in place of the designs presented here. Water-well and booster pump facilities each represent less than 1% of emissions.

Since pumping energy constitutes the overwhelming majority of the case study utility’s GHG footprint, opportunities for reducing this WDS aspect were closely examined. Decreasing the water pressure, through fixed-outlet or flowmodulation devices, in water delivered to customers could reduce emissions, but would violate fire flow requirements, significantly increasing the utility’s insurance expenses [37, 38]. Upgrading pumping equipment to increase efficiency also has large potential emission and cost savings [39]. As the case study utility experiences such large losses in distribution, and with leak reduction becoming a major focus for utility and city managers in North America [37, 16], this study focused on determining the GHG savings potential in leak reduction through pipe replacement.

5. GHG abatement through leak reduction

As discussed in LCI results, the utility experiences a high level of water loss in distribution (40% of total volume). However, as revealed in the introduction, losses approaching or over 30% in WDSs are common. To overcome substantial losses such as these, a significant investment in operational spending is necessary, but it is cost effective in regions where utilities require significant inputs to treat and transport water to customers. However, these investments can be viewed from a different perspective when incorporating GHG emissions into the overall decision-making. Although leaks are dependent on many factors (pipe materials, soil conditions, location within a network, pumping dynamics), this study takes a general approach to reducing leaks and determining benefits as described later in the text.

The case utility communicated an interest in understanding how the GHG emissions from leaks and rehabilitation inputs could affect pipe replacement scheduling. In response, the authors created a tool to determine when pipe replacement inputs would equal emissions accrued in operation of an isolated pipeline. Accrued emissions for a given analysis period can also be calculated. The tool allows a user to vary analysis length, electricity mix, leak increase rates, pumping energy dynamics, pipe materials, construction techniques, and interest rates for treatment and pumping energy discounting. Construction techniques include open-trench and HDD methods. The tool accrues emissions from head losses and leaks. Leaks include the embedded emissions from pumping energy and treatment in lost water, which dominate total emissions. Replacement inputs include construction equipment, pipings materials, asphalt, and aggregates as defined by the user inputs. The tool and sample results are further detailed in the supplementary data (available at stacks.iop.org/ERL/9/024017/mediad).

The tool results, where optimal pipe replacement is based on GHG emissions, show the pipe should operate without replacement no more than 20 years. Using HDD methods in place of traditional open-trench pipe replacement reduces this maintenance rate by almost half. One life-cycle study focusing on minimizing energy consumption found 50 years to be the optimal replacement time [10]. The case study utility can only replace about 1.6 km (1 mi) of pipe per year due to budget restrictions, resulting in a replacement rate of 300 years for pipes within the system. This replacement rate is similarly high to the reported US average of 200 years [40]. A recent study suggests that in the coming decades pipes should be replaced at a rate 1/3 of the current US average [40].

The tool results can be placed in a wider context by calculating the carbon abatement costs (CACs) of sample leak reduction options. Emission abatement costs are used to compare emission reduction alternatives [41]. Using the tool developed for the breakeven analysis, the accrued emissions from maintaining a given allowable leak rate for an isolated pipe length can be calculated. The replacement rate is the time period for the leak increase rate to achieve the maximum leak level. These accrued emissions, based on the emissions from leaks and recurring pipe replacement, are combined with the economic cost of maintaining the leakage level.

The economic costs are based on the number of necessary pipe replacement efforts, the case study utility’s estimated cost of replacement ($0.6 million per km ($1 million per mi)), and the treatment and pumping energy inputs saved by avoiding leaks. The pumping energy electricity prices were based on the case utility’s purchasing price. Treatment costs were based on the case utility’s chlorination process. Ramping up pipe replacement efforts could see increased costs, which are discussed later in the study, but it is assumed that maintaining a lower maximum leak rate over longer periods of time will reflect the average cost of replacement per unit length but with greater frequency. CACs are determined for leak rate reduction scenarios based on the same inputs used in the breakeven analysis over a 50-year analysis period.

Discounting was included for treatment (0.5% annual interest rate), pumping energy (1%), and maintenance costs (1%). The interest rates reflect the low variations over time in these costs experienced by the case utility. The case utility determines spending efforts by budget allocations and does not utilize a strict minimum attractive rate of return (MARR) in planning. A MARR would be applicable for larger utilities where high-cost projects would necessitate public funding, potentially through issuing bonds. It should be noted that all utilities have different attributes and the case utility’s processes cannot be applied everywhere.

Table 2 shows the cost per metric ton of CO$_{2}$eq for several leak reduction options for the case study utility. Each leak rate change option represents a change from the maximum allowable loss rate in distribution for a utility, where a 40%–5%
leak rate change represents a 35% reduction. These leak rates are assumed to be distribution losses resulting from leaks, which can be controlled through pipe replacement. Distribution losses beyond leaks, such as metering errors, unauthorized consumption, and background losses, are not included in the analysis.

Table 2 reveals that based on attaching electricity, treatment, and replacement costs for an isolated segment of pipe, without considering potential network effects, both economic and GHG benefits can be achieved by reducing leaks for some situations. As a reference, the average US drinking water retail price is about $2 per thousand gal [42]. It should be noted that employing HDD replacement methods can also significantly reduce direct replacement costs [43].

Reducing leaks could be an attractive GHG reduction effort when compared to other existing technologies that could be potentially employed by utilities and policy makers. Switching to residential solar in place of natural gas for electricity has a CAC of $200 t^{-1} CO_2 [44]. Switching to wind electricity from natural gas ranges from $60 to $40 t^{-1} n \ CO_2 [45–47]. Water-specific options could include promoting water conservation and increasing pump efficiency. A previous study found reducing pressure to have a CAC range of $57–72 t^{-1} CO_2 [38]. This type of analysis will become more useful if carbon cap-and-trade programs become the norm in the United States, where utilities can assess their GHG emission reduction efforts with the market price for trade.

Table 2’s results can be represented visually to compare economic costs and GHG emissions of maintaining different leak levels, as shown in figure 1. Results shown in figure 1 are based on the same tool inputs as table 2. The results are varied by different leak increase rates. A leak increase rate typical of the case utility would range from 0.5 to 0.8%.

As the results in table 2 were based on a 50-year analysis period, the emissions were capped at 50 years. The curves show that diminishing return on investment exists for leak levels below 10%, and economic costs and GHG emissions increase as replacement inputs exceed the savings of avoided losses. Different utilities and pipes within the same utility will behave differently, which creates uncertainty in the results. This is further discussed in the following section.

**Figure 1.** Economic costs and GHG emissions associated with maintaining different maximum leak levels. Results are varied by different leak increase rates.

### 6. Pipe material selection

The pipe materials used by the case study utility, detailed in tables S4–9, were assessed for both economic costs and GHG emissions for a 50-year timeline in the same fashion as the leak reduction options. The GHG emissions were based on estimated leaks and maintenance inputs to repair expected breaks. Expected breaks were modeled from existing studies [48, 49]. The structural performance of pipes was based on an analysis conducted by the case utility. The replacement costs were based on calculated material costs and the case utility’s reported replacement costs.

These results were assessed to determine if multiple efficient options for piping existed based on the analysis. Using Pareto efficiency to assess different pipe options is a simple application of the methodology to identify the optimal material alternatives when both minimizing costs and GHG emissions are objectives. This evaluation technique isolates a set of ideal alternatives when given several options to optimize multiple criteria [23]. Figure 2 shows the Pareto results of the different piping materials assessed in this study.

The analysis reveals that PVC and DICL are optimal options for the case study utility in operations. The case study utility uses mostly DICL in new pipe installations as the performance of the material is preferred. The case

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**Table 2.** Carbon abatement costs for different leak rate change options for the case study utility. MG denotes million gallons (that passes through the pipe annually). Emissions are based on pipe replacement, frictional losses, pumping energy, and treatment inputs.

| Leak rate change option | Cost incurred ($/MG) | Avoided ton (CO2eq/MG) | CAC ($ t^{-1} CO2eq) | Cost per avoided losses ($/gal) |
|-------------------------|----------------------|-------------------------|----------------------|--------------------------------|
| 40%–5%                  | $7.97                | 0.14                    | $57.53              | $0.00002                       |
| 40%–10%                 | $11.84               | 0.12                    | $98.97              | $0.00004                       |
| 40%–20%                 | $10.15               | 0.08                    | $131.98             | $0.00005                       |
| 30%–5%                  | $3.36                | 0.08                    | $42.69              | $0.00001                       |
| 30%–10%                 | $7.23                | 0.06                    | $120.93             | $0.00004                       |
| 20%–5%                  | $2.18                | 0.06                    | $35.40              | $0.00001                       |
| 20%–10%                 | $1.70                | 0.04                    | $39.687             | $0.00002                       |
utility has recently used PVC extensively, but has experienced problems with proper installation, which can lead to structural performance issues.

This analysis has inherent uncertainties due to a lack of data and pipe behavior understanding. The pipe bursting prediction model and leak rates applied to the pipe materials were based on the case utility’s feedback and not a quantitative analysis, which could limit the accuracy of the results. Head losses from pipe friction were not significant in this analysis. Pipes will also perform differently over time based on several variables: soil conditions, environmental stresses, pumping dynamics, and location within a system.

Previous work has documented the human health impacts of employing PVC materials for building and infrastructure applications. PVC was found to have the greatest concentration of carcinogens of pipe materials, mainly due to resin materials, creating risks in production, maintenance, and end of life [50]. PVC products also leach volatile organic compounds and phthalates during use that are toxic, particularly for exposed children [51]. These considerations, however, are outside the scope of this study.

7. Regional greenhouse gas emission reduction scenarios

US global-warming-related policies being considered or already in place, such as in California, are forcing industries to incorporate GHGs and other air emissions as part of their decision-making [52]. WDSs do not immediately come to mind when discussing GHG reduction policies, where power plants and other manufacturing facilities represent substantial emissions. However, as major consumers of electricity [7–9], emissions from WDSs will be targeted as a significant source for GHG reduction.

In its 2008 scoping plan, the California Air Resources Board (CARB) estimated that almost 5 million tons of CO$_2$eq could be saved by the state’s water infrastructure, with over 40% of this number (2 million tons of CO$_2$eq) coming from potential energy efficiency improvements [52]. The case study utility’s LCI results were combined with California-specific transmission, distribution, and treatment data to create GHG intensity estimates [45]. California-specific pipe replacement costs were found to be almost 2.5 times higher than those of the case study utility [53].

Texas is another state where water scarcity and a water-intensive economy create a strong focus on minimizing losses in WDSs. As discussed previously, Texas currently loses 13% of water in distribution [13]. In both Texas and California, publicly available regional-specific consumption and water source data can be combined with the methods employed in the LCI to create region-specific GHG intensities of drinking water. The steps taken to achieve this are detailed in the supplementary data (available at stacks.iop.org/ERL/9/024017/mmedia). For both states, despite the average state water losses being significantly less than the case study utility, the CACs for reducing leaks can be determined. Figure 3 shows the CACs for reducing losses to 5% for three estimates in California and Texas based on the best available LCA and water consumption data. The three cases reflect the high, low and best estimates for GHG abatement potentials in the different states. In all three cases the CACs are based on the replacement costs of pipes only.

The variations in CACs are a reflection of the abatement potential and diminishing return on investment, where replacement costs begin to exceed savings, in reducing losses through pipe replacement. The costs vary from positive to negative in this analysis because the different energy intensities used in transporting water for the different cases yield different electricity costs savings. Utilities that have access to exact numbers for electricity and treatment costs can create accurate numbers for savings as shown in the case utility’s example.

In California WDSs, reducing leaks by 5% (the best estimate avoids 3.4 million tons of CO$_2$eq yr$^{-1}$) annually exceeds the CARB estimation of GHG abatement through improved energy efficiency. As discussed previously, utilities can vary considerably in design and operation. This is especially true of treatment and pumping inputs. The methods presented in this section reveal what can be inferred about a state or utility’s GHG footprint and potential for savings by applying the best data available.

8. Discussion

WDSs with similar circumstances as the case utility should first target pumping energy and reducing leaks in addressing their own GHG footprint. Although the case study utility experiences a high volume of water losses to leaks and low treatment inputs, several aspects of the case study utility are similar to other US WDSs. Many portions of the United States rely on nearby freshwater sources and distribute through aging pipeline systems. The dominance of pumping energy in GHG footprints have been found in related studies that assess WDSs with freshwater sources [21, 25].

Existing research has shown that a major infusion of funding in US WDS maintenance will be difficult as current economic costs of underfunding these WDSs does not
garner enough attention [40]. However, this is not the only problem WDSs face in implementing major leak reduction programs.

The case utility, as well as all WDSs with substantial losses, must cope with societal costs that make leak reduction a difficult challenge. With the necessary funding, a sizeable work crew would have to be established, one that may be unsustainable for the utility and city as a whole. Assuming the bulk of the pipe replacement could only be done in warm weather, this work force could only be employed for roughly half the calendar year for regions that experience freezing temperatures. Few skilled laborers will find this type of work schedule acceptable. The case study utility has run into similar problems when trying to find contractors to perform non-invasive pipe construction. Service interruptions, altering traffic patterns (with increased congestion), and aesthetic effects all come with ramping up pipe replacement. The burden on the public could result in sizeable backlash that could hamper the utility’s public image or ultimately change public policy to impede the utility’s leak reduction efforts. However, as a positive public relations benefit associated with leak reduction, the case study utility would be viewed as a good custodian of natural resources and could use this to bolster its public image.

The results of the LCI and sample calculations from the breakeven tool are unique to the case utility but have elements that can be applied generally to WDSs. Construction methods, water storage and well facilities, and pipe materials from the LCI are commonly found globally in WDSs. The breakeven tool allows for significant user variations to model expected emissions and costs for an isolated pipe length.

Every drinking water utility, both in the United States and worldwide, will possess the bulk of their GHG emissions in treatment and pumping. For any WDS, reducing unnecessary water losses in transmission and distribution avoids compounding the impacts of these processes, a ‘low-hanging fruit’ that can achieve substantial GHG savings and potentially economic costs too. This will become even more relevant as growing populations are forced to access new and lower quality water sources, increasing the embedded emissions and value of drinking water.

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