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The costs of direct and indirect potable water reuse in a medium-sized arid inland community

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ABSTRACT

Planned potable water reuse can improve the reliability of water supplies by providing drinking water from wastewater. While the US government predicts near-term conflict over water in numerous small-to-medium-sized arid inland communities, knowledge gaps exist regarding the cost of potable reuse for this context, making it difficult for water managers to understand the feasibility of options. This research aims to inform decision-making about potable reuse in small-to-medium-sized arid inland communities by estimating the total present worth of several indirect and direct potable reuse treatment scenarios. We find that the present worth for indirect potable reuse that uses an aquifer as an environmental buffer is only slightly higher than for direct potable reuse that includes drinking water treatment; the present worth of both of these scenarios is higher than for direct potable reuse that does not include drinking water treatment due to the additional pumping and piping requirements. Further, scenarios including reverse osmosis for advanced treatment have significantly higher present worth values than those including ozone/biological activated carbon. All reuse scenarios considered cost far less than purchased water. Costs aside, any scenario must also be acceptable to regulators and the public and approvable from a water rights perspective.

1. Introduction

Sustainable communities must balance current development and resource use with the needs and quality of life of future generations. Critical among both current and future needs is access to adequate water supplies of acceptable quality. Communities can choose between numerous supply- and demand-side options to improve the sustainability and reliability of potable water supplies [1–3]. Indirect and direct potable reuse (IPR and DPR, respectively) are two supply-side options that hold particular promise for significantly increasing “water productivity” by recovering drinking water from purified wastewater [1]. With planned IPR, highly treated wastewater treatment plant (WWTP) effluent is held for a specified amount of time in an environmental buffer, such as an aquifer or reservoir, prior to being directed to groundwater treatment or a drinking water treatment plant (DWTP) [4]. With DPR, no environmental buffer is included, and treatment can take place either in separate WWTP and DWTP systems, or in a single advanced treatment system [4–7].

With increasing population and development pressures, it is not surprising that IPR and DPR are of increasing interest to communities with exceptional water scarcity. Numerous IPR systems exist around the world, and while IPR may reduce water contamination risk by providing dilution and additional biological and physical treatment [8], it is inefficient in that highly treated water may be degraded when directed to an environmental buffer, and therefore wastes energy and resources by treating the same water twice [7,9]. IPR has the potential to be more expensive than DPR and have a greater carbon footprint because of additional piping, pumping, and treatment; however, the cost comparison is context specific since it depends on various site factors and the location of the environmental buffer [5–7,9,10]. Far fewer DPR systems exist worldwide; while a facility in Windhoek, Namibia has been operating successfully in various configurations since 1968 [11], municipal-scale DPR is relatively new to the US. Facilities in operation or design in Texas and New Mexico (e.g., those in Big Spring, TX, and Cloudcroft, NM) have paved the way for increased awareness and discussion of DPR as a potentially reliable and economical option and have led to development of guidance and regulations for implementing DPR.

Though many of the communities that may be interested in the possibility of planned potable reuse are small-to-medium-sized and

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scattered throughout the inland Southwestern US [12], most of the research on potable reuse has focused on large coastal communities with relatively high mean household incomes [13], such as Orange County, Los Angeles, and San Diego, California. Potable reuse options may be different for larger, wealthier coastal communities as compared to smaller, less affluent inland ones − not only in terms of the technologies and process configurations that are appropriate, but also in the ability and/or willingness-to-pay for the required technologies. Costs are a significant concern because reclaimed water may be expensive relative to the artificially low water prices to which the public has grown accustomed [7]. Also, potable reuse implementation, especially DPR, involves operation and maintenance of a high-tech treatment system, which requires technical expertise that some smaller communities may lack [14].

2. Project objectives and overview

2.1. Project objectives

This paper aims to contribute to the scant literature on potable reuse in small-to-medium-sized arid inland communities by developing an estimate of the costs of potable reuse options and identifying constraints that must be addressed when considering implementation of future reuse projects. Experts have suggested that numerous communities and local contexts be studied for a broader understanding of water management alternatives [15], and there is little research on planned potable reuse in New Mexico, despite the DoI's prediction that water conflict in the state's urban centers will be "highly likely" by 2025 [12]. Bernalillo County, NM, was selected as a case study for this research because it possesses a set of characteristics that is different from previous case studies found in the literature: (1) it is a medium-sized inland community with significant potential for water conflict [12]; (2) the population is highly diverse with a relatively low mean household income [13]; and (3) the location presents technical challenges not found in coastal areas. The focus was on the Albuquerque-Bernalillo County Water Utility Authority (ABCWUA), which is the largest water utility in NM and provides water supply and wastewater collection and treatment for over 500,000 people [16]. Managers at the ABCWUA expect that IPR and/or DPR may become parts of the potable water portfolio within approximately a decade.

Since most IPR and DPR research has focused on large coastal communities, knowledge gaps exist regarding the costs associated with planned potable reuse technologies and treatment process configurations that are appropriate for an arid, inland context. As a result, some public utilities in arid, inland communities are struggling with long-term planning and selection of appropriate strategies to mitigate shrinking water supplies while minimizing constraints to sustainable community planning. Research is needed to better understand which potable reuse options are optimal for arid, inland communities, including an examination of how these options' costs compare. The focus of this study is on the IPR and DPR treatment schemes appropriate for the inland context and their costs as reported in the peer-reviewed and grey literature; the treatment schemes included were not modeled or otherwise evaluated to understand or comment on the differences among them in produced water quality. The results of this study will be useful to Bernalillo County and the ABCWUA as well as other mid-sized inland communities throughout the arid Southwest. Our intent is that water planners and policymakers in arid inland communities can use the study results to help them consider the costs and constraints of various potable reuse options. Ideally, in addition to costs, they would have access to a decision tool that would aid in evaluating various water resource development strategies, given climate and demographic uncertainties [17]. However, knowledge of the estimated costs of different options will provide a starting point for planning and evaluating the feasibility of reuse.

2.2. Project overview and scenarios considered

Advanced treatment process configurations for potable reuse facilities usually include reverse osmosis (RO), although the technology has three major drawbacks: (1) high energy requirements, (2) the environmental challenge of concentrate disposal [18], and (3) a loss of approximately 15–20% of the feed water, an important limitation in communities facing serious water shortages. Coastal communities can dispose of concentrate into the sea [7], but inland communities must find alternative disposal options. It is reasonable for inland communities to consider advanced treatment options that do not include RO [6] in order to avoid the technology's drawbacks [7,45], in part because it is possible that these drawbacks may result in higher costs that are unaffordable to smaller communities, as will be discussed later in this paper.

For example, inland communities could consider an advanced treatment train for potable reuse that includes ozone plus biofiltration or biological activated carbon (O_3/BAC) as an alternative to one that includes RO; the full treatment train might look something like O_3/BAC followed by ultraviolet (UV) disinfection, granular activated carbon, UV and an advanced oxidation process (AOP), similar to what has been discussed in the literature [7]. Such a train would likely use less energy and would avoid creation of a waste concentrate stream [19].[1] O_3/BAC is less expensive than RO because of the reduced energy requirements, elimination of concentrate and waste management costs, and nearly 100% feed water recovery, although the actual present worth cost difference has yet to be reported in the peer-reviewed literature.

Several scenarios to increase the potable water supply were considered in this study; these scenarios complement those considered by Raucher and Tchobanoglous [20]. The scenarios considered were inland IPR and DPR, as discussed by Tchobanoglous et al. [6], and the purchase of water rights. *Scenario 1* represents the municipal purchase of water rights in the Middle Rio Grande Basin, *Scenario 2* represents IPR, and *Scenarios 3 and 4* represent DPR (see Fig. 1 for more detail). Two options for advanced treatment were included for each of Scenarios 2–4, both of which included microfiltration (MF) as a pretreatment step: Option A consisted of RO plus UV, and Option B consisted of O_3/BAC followed by UV, as discussed in Lee et al. [19] and Tchobanoglous et al. [6].[2] The study discussed here did not consider log removal credits for planned IPR projects in which purified wastewater is discharged to an aquifer for intended subsequent reuse because the regulatory requirements for such a system are not yet established in any state except California to the authors' knowledge. California has established regulations for IPR projects for both surface water and ground water applications [21]. In both scenarios a high degree of wastewater treatment is required including log reductions of 12, 10, and 10 for enteric virus particles, cryptosporidium oocysts, and giardia cysts, respectively. Other states regulate wastewater discharge to surface waters through NPDES permits issued under the federal Clean Water Act while ground water discharges are covered under state ground water quality regulations. In both cases, subsequent reuse of the water is not considered in federal or state regulations pertaining to the discharge.

For each reuse scenario and treatment option included in this study, capital costs (including construction, engineering, and equipment) and operations and maintenance (O & M) costs (including electrical, chemical, labor, and other ongoing expenditures) were considered; cost

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[1] Whatever technology is used, reliability and monitoring are critical to identifying off-spec water before it reaches the distribution system in order to protect public health; however, these topics are outside the scope of this paper.

[2] Advanced treatment that included other options, such as AOPs, were also considered for inclusion in this study, but these two were ultimately selected for comparison since their performance was tested and compared by [19] and found to be nearly equivalent for the parameters tested. However, AOPs provide better removal of some compounds than UV alone. For this reason, it is important to consider its inclusion in the treatment train, as described in the previous paragraph.