Article

Benefits, costs and enabling conditions to achieve 'water for all' in rural and remote Australia

Ana Manero [1], Wiktor Adamowicz [2], Sonia Akter [1],
Alaya Spencer-Cotton [1], Peter J. Coombes [1], Paul Wyrwoll [3],
James Horne [4], Nina Lansbury [5], Sandra Creamer[5],
Katherine Selena Taylor [1], Safa Fanaian [1] & R. Quentin Grafton [1]✉

Australia will not meet Sustainable Development Goal target 6.1, to "achieve universal and equitable access to safe and affordable drinking water for all" by 2030, unless water service provision is improved to hundreds of small (less than 10,000 residents), rural and remote (SRR) communities. We have estimated the national benefits of a programme to upgrade drinking water services to ensure 'good quality' for 395 Australian SRR communities using a stated preference survey of 3,523 participants reflective of the Australian population. Using multiple model estimates, we calculated the willingness to pay at between AU$324 and AU$847 per Australian household per year for 10 years. Aggregating across the relevant Australian population, we calculated the aggregate willingness to pay for water quality improvements at AU$1.2–4.7 billion yr^{-1}, or AU$8.3–33.2 billion as a 10-year net present value. We further estimated the capital and operating costs to provide 'good-quality' drinking water in the 395 SRR communities under three scenarios; the costs range from AU$0.51 to AU$3.29 million per community and, in total, from AU$0.2 billion to AU$1.3 billion.

The Sustainable Development Goal (SDG) target 6.1 is to "achieve universal and equitable access to safe and affordable drinking water for all" by 2030[1]. In most high-income countries, over 90% of the population has access to safely managed drinking water[2]. Nevertheless, gaps persist in service provision and monitoring even in the Global North and predominantly between large metropolitan areas and remote communities, including in countries such as the United States, Canada and Australia[3–7].

In Australia, unsafe, unacceptable and unreliable drinking water exists[8–12] in small, rural and remote (SRR) communities. The most comprehensive Australian dataset on national drinking water quality gaps[3] identified 395 SRR communities (under 10,000 residents) in 2018–2019 where drinking water reportedly failed to meet guideline values for health-based and aesthetic characteristics constituting 'good quality' (Fig. 1), as defined under the Australian Drinking Water Guidelines[13] (ADWG; see Methods for definitions). In addition, 500 communities (>50 people) and over 1,000 homelands and outstations (<50 people) have recently been identified as completely lacking water quality monitoring[14]. The exact number of communities and total population exposed to a substandard quality of drinking water are unknown because of monitoring and reporting gaps[3]. For the SDG 6.1 target, the Australian government reports that some 2%

¹Crawford School of Public Policy, Australian National University, Acton, Australian Capital Territory, Australia. ²Department of Resource Economics and Environmental Sociology, University of Alberta, Edmonton, Alberta, Canada. ³Crawford School of Public Policy, Institute for Water Futures, Australian National University, Acton, Australian Capital Territory, Australia. ⁴James Horne and Associates, Canberra, Australian Capital Territory, Australia. ⁵School of Public Health, The University of Queensland, Brisbane, Queensland, Australia. ✉e-mail: quentin.grafton@anu.edu.au
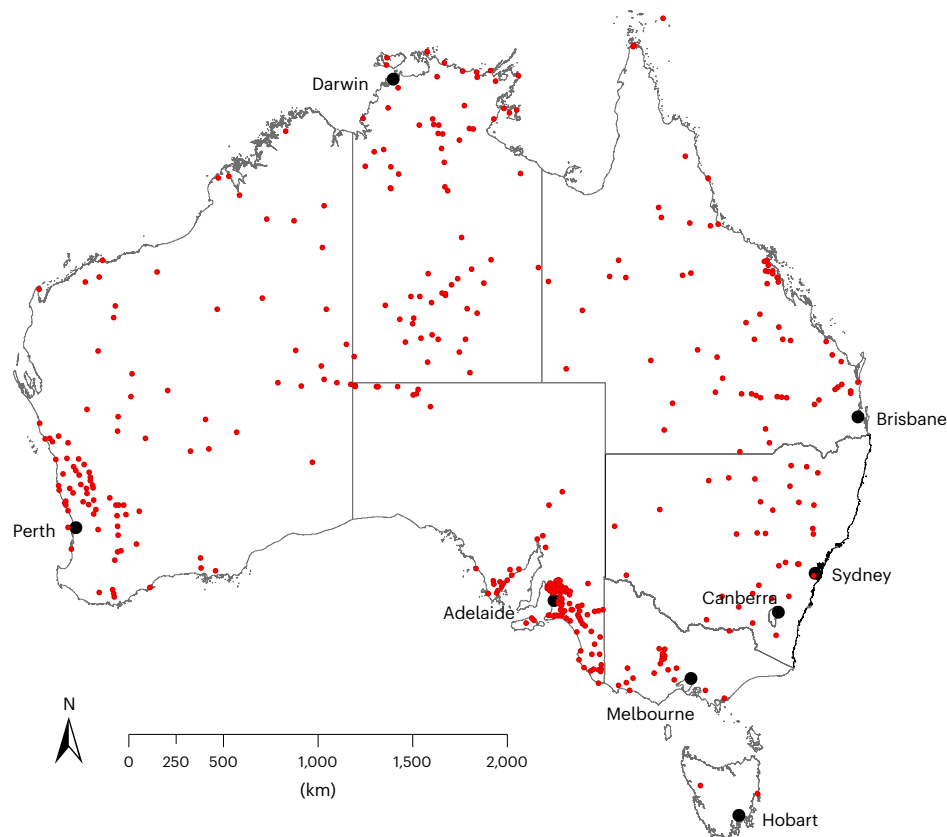
Fig. 1 | SRR communities with known exceedances against drinking water guideline values. Map showing the 395 communities of up to 10,000 inhabitants where, in 2018–2019, at least one exceedance was recorded against the guideline values of the health-based and six aesthetic characteristics defining 'good water quality' under the ADWG. The locations in New South Wales reflect non-compliances with chemical and/or microbial parameters. Other parameters have been excluded due to a lack of publicly accessible information. Data from ref. 3.

of the Australian population lack access to "safely managed drinking water services"[15].

The elevated costs of ensuring good-quality water and challenges with monitoring and maintenance in SRR communities have impeded efforts to improve water service outcomes[16]. Another challenge is that water infrastructure is capital-intensive, requiring long-term planning that makes it difficult for SRR households to pay the full capital cost of water service improvements[17–19]. Consequently, cross-subsidies from rich to poor or industrial to domestic water users are frequently used to support cost recovery for SRR water services[20].

A key policy challenge to delivering the SDG 6.1 target is that the beneficiaries of improvements in drinking water quality do not necessarily pay the full costs of improved water services. In Australia, the principal beneficiaries of improved drinking water quality are remote from major urban centres whose residents provide the bulk of tax revenues for the provision of public services. Thus, it is necessary to estimate the willingness-to-pay (WTP) of Australians, including in urban centres, to deliver drinking water that achieves the ADWG for all (in urban, rural and remote communities) and the associated capital and operating costs if decision-makers are to effectively evaluate trade-offs and competing investment priorities.

We have estimated the WTP of Australian residents for the domestic provision of 'good-quality' drinking water for some 260,000 residents of the 395 SRR communities who lacked access to the 'ADWG Good' definition of a basic level of drinking water quality in 2018–2019[3] (Fig. 1 and Methods). Our WTP estimates are payments for an improvement in public services[21] that includes the provision of safe drinking water[22,23] and represent an Australian-wide estimate of the societal benefits of improving known water quality issues. Our WTP estimates were obtained from a stated preference[24] survey of 3,523 nationwide

Australian participants who responded to questions about an intervention to improve the provision of drinking water services.

In a separate but complementary analysis, we estimated the incremental capital and operating costs to improve drinking water supply services in the 395 non-compliant SRR communities. Beyond quantifying the benefits and costs, we reviewed the enabling conditions, especially within Indigenous communities, to deliver improved water services that meet the needs of SRR communities and respects their free, prior and informed consent. We conclude with guidance about the benefits, costs and enabling conditions to deliver water to all Australians and possible insights for other countries.

Sample

Our estimated benefits come from a national sample of Australian adult (18+ years) residents (n = 3,523; see Methods for details on data collection) that is reflective of observable demographic characteristics, including age, gender, location, income and education levels, of the Australian population (Supplementary Table 1).

Over 4.9% of participants identified as Aboriginal and/or Torres Strait Islander, a higher figure than the 3.8% national average[25]. While residents in capital cities accounted for two-thirds (67%) of the sample, 42% of participants indicated that they live or have lived in a small town (under 10,000 residents) in regional or remote Australia. Most participants (85%) reported that they are connected to a municipal water supply system (10% replied "I don't know") and consumed "tap water" (77%) as their main source of water for drinking purposes.

Nearly 65% of survey participants reported experiencing at least one water issue with their domestic water supply, such as bad taste or smell, mineral build-up or becoming sick. The frequency of these water quality issues was relatively low: only 6–7% of participants had
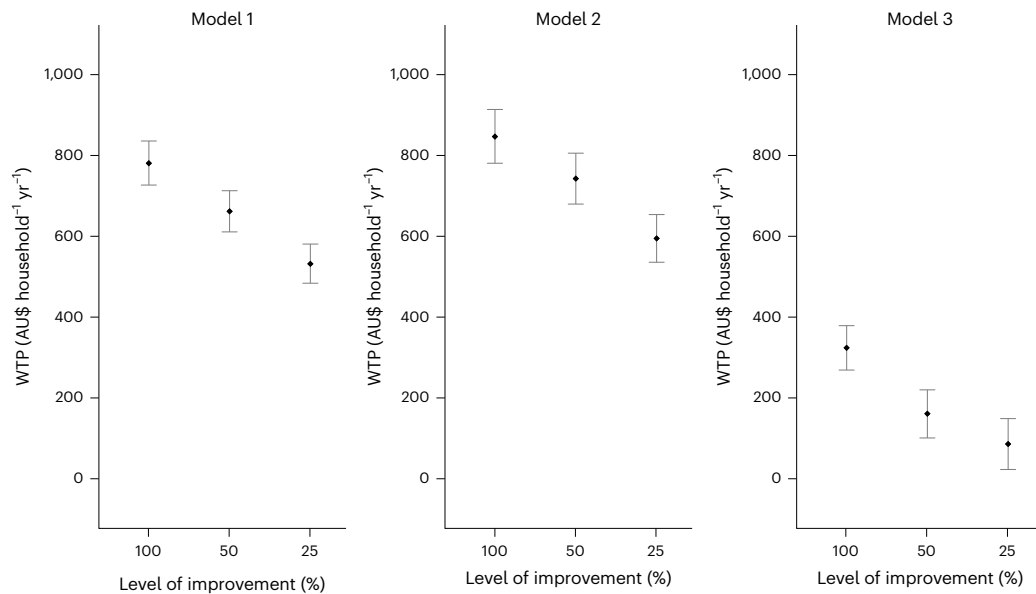
Fig. 2 | WTP for improvements in drinking water quality. Parametric mean WTP (data points) and 95% confidence intervals (error bars) for three proposed levels of improvement, that is, 25%, 50% and 100%, in drinking water quality for 260,000 people living in the 395 SRR communities that were known to be exposed to substandard drinking water in 2018–2019. Model 1: full sample; Model 2: only payment consequentiality; Model 3: only payment consequentiality and tax attendance, certainty calibration.

experienced a water quality issue over the previous month. In relation to social and environmental concerns, 40% of survey participants indicated that they were "very or extremely concerned" about "lack of good-quality drinking water", and 46% about "having enough water for agriculture in the future" and "the impact of climate change".

Models

We used attribute-only, nonlinear probability models to explain the probability of a "Yes" or "No" outcome of a vote to improve the supply of good-quality drinking water (see details and equation (2) in Methods). The results from nine models with different specifications and population subsamples are presented in Supplementary Table 4. The main reasons why people chose to vote "Yes" or "No" are summarized in Supplementary Fig. 3.

In our survey, each participant responded to two questions (that is, choice tasks) incorporating varying levels of (1) improvement in the coverage of improved drinking water quality in SRR communities and (2) a tax increase to pay for the proposed improvement (Methods). Model 1 was estimated with the full sample of 7,046 observations (two questions per participant). Model 2, with a subsample of 4,710 observations, considered the possibility that some responses may be biased because of the hypothetical nature of the survey questions. Consistent with theory and empirical evidence[26,27], we adjusted for one possible form of hypothetical bias by restricting the sample to only those participants who stated that their survey vote was 'consequential'. Consequentiality, in this case, is the condition whereby participants perceive a non-zero probability that their responses will influence actual decisions regarding the outcome and that they may be required to pay for the improvement in drinking water quality in SRR communities[28]. That is, Model 2 included only participants who agreed or strongly agreed with the statement "If the Australian Government implements the drinking water program: I believe my household will have to pay a tax increase to pay for the program".

Model 3 departed from Model 2 and applied two further ex post approaches to mitigate response biases: correction for attribute non-attendance and certainty calibration[29]. With a subsample of 4,222 observations, Model 3 combined observations from participants who agreed or strongly agreed to the statement "If the Australian Government implements the drinking water program: I believe my household will have to pay a tax increase to pay for the program" (that is, only payment consequentiality) with observations for which respondents indicated that they had "considered the tax" when making their voting decision (that is, excluding tax non-attendance). Further, certainty calibration was applied to transform uncertain positive responses to negative votes, which is an approach that may reduce hypothetical bias[30,31]. Thus, "Yes" answers for which respondents indicated that they were "neutral", "hesitant" and "very hesitant" were recoded as "No" votes.

Across the full sample, the percentage of "Yes" votes varied between 34% (25% improvement and AU$1,000 tax increase) to 86% (100% improvement and AU$50 tax increase). Across the subpopulation of Model 3, the support ranged between 15% (25% improvement and AU$1,000 tax increase) and 74% (100% improvement and AU$50 tax increase). A graphical representation of vote outcomes is available in Supplementary Fig. 1. Across all models, the coefficients of the proposed level of tax rise for households were statistically significant and negative. That is, and as expected, the probability of a "Yes" vote decreases as the tax level increases.

The levels of proposed water quality improvements were significant predictors of the vote outcome across all models (Supplementary Table 4). That is, there is a preference for greater coverage (50% and 100%) in the provision of good-quality drinking water compared with a 25% baseline level of improvement in the survey instrument. For Models 1–3, differences between 100% and 50% were also tested and found to be statistically significant, at the 95 level or higher (Supplementary Table 5). Consistent with non-market valuation theory and patterns of utility maximization, participants preferred options that provided greater benefits, thus satisfying the classical 'scope test'[32,33].

WTP for improvements in drinking water quality

WTP estimates were calculated as the parametric mean (which coincides with the parametric median in probit models[34]) for the relevant sample with a 95% confidence interval for the three possible levels of coverage for water service improvement (25%, 50% and 100%) and for all models (Experimental design and WTP estimation). The mean WTP and confidence intervals for Models 1–3 are presented in Fig. 2, while

Table 1 | Aggregate WTP for the programme to improve drinking water quality in SRR communities across Australia

Aggregation assumptions	Across all Australian households	Assuming zero WTP for non-respondents[a]
Number of willing-to-pay households (million)	9.48	6.05 (Model 1) 4.04 (Model 2) 3.62 (Model 3)
Annual aggregate WTP (AU$ billion yr⁻¹)		
Model 1: full sample	7.40	4.72
Model 2: payment consequentiality	8.03	3.42
Model 3: only payment consequentiality and tax attendance, certainty calibration	3.07	1.17
Present value of aggregate WTP over 10 years (AU$ billion)		
Model 1: full sample	51.99	33.17
Model 2: payment consequentiality	56.39	24.05
Model 3: only payment consequentiality and tax attendance, certainty calibration	21.57	8.25

The results are based on the WTP for 100% improvement in drinking water quality. [a]Our survey had a completion rate of 63.8%, which means that there is no information regarding the voting preferences of the 36.2% who did not complete the survey or were disqualified (that is, non-respondents). A low-end WTP aggregate assumes that non-respondents have zero WTP[36]. Thus, for aggregation purposes, we applied the 63.8% completion rate (Survey design) to estimate that there are 6.05 million Australian households who would be willing to pay for the proposed programme. We applied further proportional reductions based on the population subsamples meeting the criteria for Model 2 (67% of respondents were in the 'payment consequentiality' category) and Model 3 (60% of responses were in the 'payment consequentiality' and 'tax attendance' category).

WTP estimates for all nine models (including non-parametric means and medians) are reported in Supplementary Table 4.

The mean WTP for a policy intervention to deliver full improvement (100%) ranged between a low estimate of AU$324 for Model 3 (only payment consequentiality and tax attendance, certainty calibration) and a high estimate of AU$847 for Model 2 (only payment consequentiality).

In all nine models, the WTP was less for lower levels of improvement, but the decline was not proportional to the reduction in benefits across most models. For example, reducing the programme coverage by 50%, from total improvement to only half of the affected population, reduced WTP by 15% in Model 1 (from AU$781 to AU$662) and 12% in Model 2 (from AU$847 to AU$743). A non-proportional effect is widely observed in stated preference WTP estimates and is consistent with diminishing marginal utility theory[35].

Aggregation of WTP at the national level

Mean WTP estimates can be used to calculate the population benefits of a policy improvement[36]. The aggregation results for our study are presented in Table 1. Our sample comprised Australian residents for taxation purposes of which, in 2022, there were an estimated 18.06 million adults living in 9.48 million households[37].

For an improvement achieving good-quality drinking water across all 395 SRR communities with known water quality breaches, the aggregate Australian annual WTP was estimated to be between a low end of AU$1.17 billion yr⁻¹ and a high end of AU$4.72 billion yr⁻¹ (see the estimates in Table 1 and further details in Methods). Over the 10 years of a proposed tax increase, at a market discount rate of 7% (ref. 38), the net present value of the programme for the relevant Australian population is between AU$8.25 billion and AU$33.17 billion, as estimated with Model 3 and Model 1, respectively. Additional aggregation results based on Models 4–9 are reported in Supplementary Table 7. Given that we aggregated only across residents for taxation purposes, our results may underestimate the aggregate WTP for the entire Australian

population because the benefits to non-taxpaying residents were out of the scope.

Determinants of support for improvements in drinking water quality

People's preferences for goods and services, including those publicly provided, are influenced by heterogeneity among consumers, including socio-demographic factors[39]. Evaluation of these heterogeneities can provide valuable information about the distributional effects of the policy in question. That is, the robustness of model results can be evaluated by assessing participants' voting preferences with respect to socio-economic variables[40].

Age, household income and education levels were mostly not statistically significant determinants of the vote outcome across Models 1 and 2 (compared with their respective baseline levels; Supplementary Table 6). Gender was a statistically significant determinant in Models 2 and 3, with males being more likely to vote "Yes" than females. Across the three models, heterogeneities were present across different occupations, with primary caregivers, full-time and self-employed workers being less likely to vote "Yes" and students more likely to vote "No" compared with unemployed survey participants, who were the baseline employment status category.

Voters of the left-of-centre political parties (Greens or Labor) were statistically more likely to vote "Yes" in all three models than any other political inclinations. This is consistent with previous evidence that such political orientation is associated with a higher WTP for pro-social interventions and services under public provision[41].

Participants who were concerned about their personal finances were more likely to vote "No" and thus avoid the tax increase resulting from the proposed programme. An association between altruism and pro-environmental considerations[42] was also observed. That is, participants who were concerned about water availability and climate change in Australia were more likely to vote "Yes" for the proposed programme of improvements in drinking water quality.

Costs of improvements in drinking water quality

There are very limited publicly available cost data on water quality improvements for small water supply systems in Australia. Nevertheless, the Australian government publishes historical data relating to capital and other costs, water quality complaints and population size among other performance indicators in Urban National Performance Reports (NPRs)[43] for water utilities servicing more than 10,000 connected properties. The service areas of a utility can also include some small and very small communities with stand-alone water supply systems. Hence, the NPR data can provide a basis for estimating the costs of water supply improvements, with appropriate adjustment for the higher costs in locations that are more distant from major urban areas.

The Urban NPR data were used to estimate the additional capital and operating costs per community under three scenarios for reduced water quality complaints. We used panel data fixed effects assumptions with robust standard errors to account for potential heteroskedastic and serial correlation effects. A statistically significant relationship, as determined by the F test of the model's overall statistical significance and P-value of an individual estimator's statistical significance from zero, was estimated ($F = 0.0000$) for the changes in capital and operating expenses ($p = 0.1285$) associated with changes in the number of water quality complaints under three scenarios (no complaints, median complaints and 95th percentile of complaints per person within each community). Estimating equations for each scenario were used to calculate (Supplementary Tables 15–17) the total (capital and operating) costs per small community (<10,000 residents) to improve the quality of water supply. Across the 395 SRR communities, the average estimated total cost per community varied from AU$3.28 million (no water quality complaints scenario) to AU$0.51 million (median per capita water quality complaints scenario). To compare the WTP annual
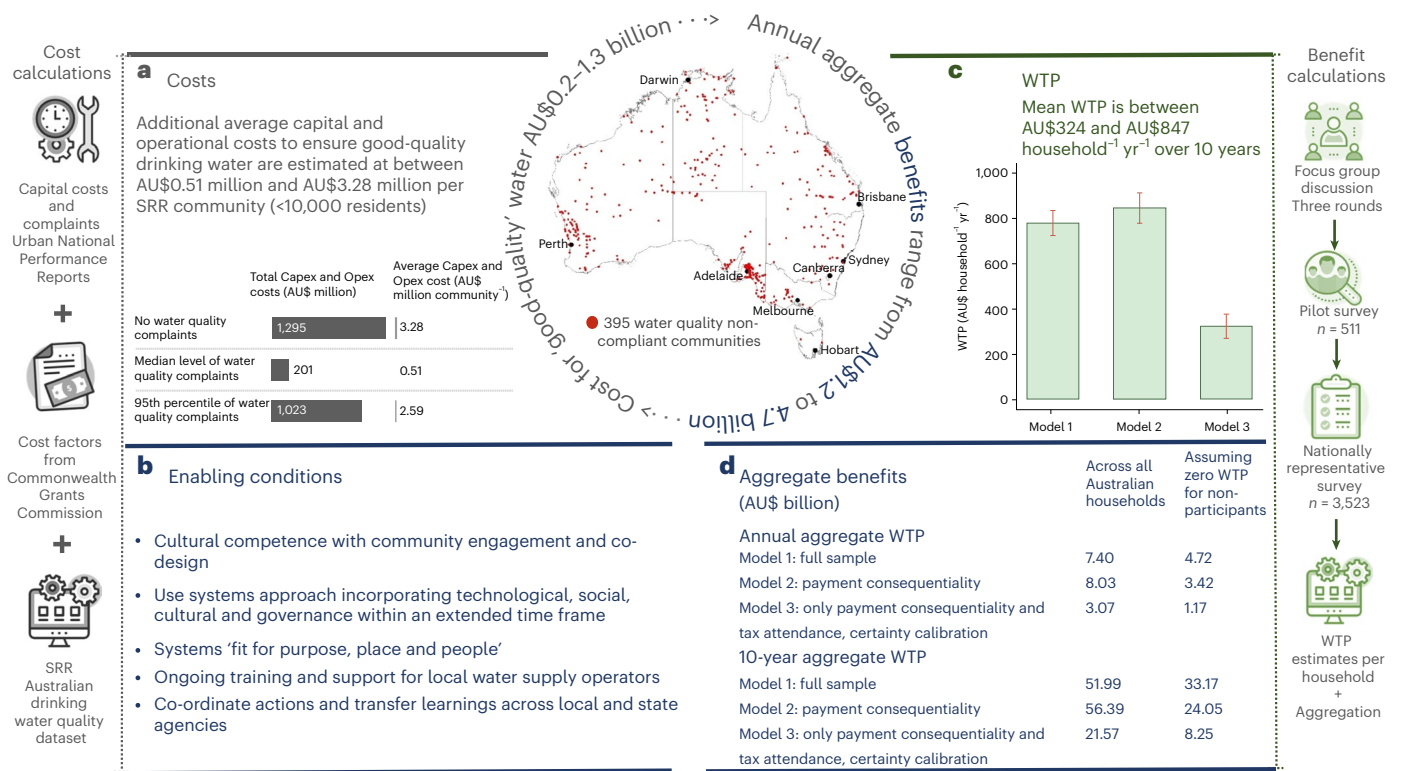
Fig. 3 | Benefits, costs and enabling conditions to achieve 'water for all' in Australia. a–d, A summary of the costs (additional average capital and operational costs) (**a**), enabling conditions (**b**), WTP (**c**) and aggregate benefits (**d**) associated with a programme to ensure 'good-quality' drinking water across the 395 SRR communities. The methods used to calculate the costs and benefits are shown on the left and right of the figure, respectively. The map shows communities of up to 10,000 residents where, in 2018–2019, at least one exceedance was recorded against the guideline values of the health-based and six aesthetic characteristics defining 'good water quality' under the ADWG. In **c**, the bars represent the mean WTP and the error bars the 95% confidence intervals for Models 1–3. Capex, capital expenditure; Opex, operating expenditure.

tax payments for 10 years to improve drinking water quality, we calculated the equivalent annual costs (capital and operating) to improve the quality of water supplies over a 10-year horizon. These equivalent annual costs per community range from AU$186 million (AU$737 per person) to AU$57.5 million (AU$227 per person; Supplementary Appendix D, Supplementary Equation (6) and Supplementary Table 18).

The Commonwealth Grants Commission (CGC) estimates levels of remoteness, population size and Indigenous communities (the so-called cost disability factors) that are designed to ensure that each state and territory is able, should it choose[44], to provide equivalent services to all communities through the distribution of federal tax revenues. These cost disability factors provide a method to appropriately adjust the costs of providing water services to communities due to their geographical distance from major urban centres. That is, we combined the CGC cost disability factors with the relationship for the capital and operating costs estimated from the NPR data to obtain an estimate of the additional capital and operating costs to provide a good-quality water supply to the smallest non-compliant SRR communities (Supplementary Appendix D).

Complementary to our cost data analyses, we used budget expenditure allocation data in the states of New South Wales and Western Australia to calculate the cost per small community to improve drinking water services. These costs are in the order of AU$3.23 million to AU$3.38 million per community and include sewerage costs (Supplementary Appendix D).

Aggregate WTP versus total costs

Assuming a zero WTP for non-participating households, aggregated WTP across the Australian population varies between AU$1.17 billion yr⁻¹ (Model 3) and AU$4.72 billion yr⁻¹ (Model 1), equivalent to a net present value of AU$8.25 billion and AU$33.17 billion over 10 years, respectively, for Model 3 and Model 1. The total capital and operating costs for all 395 communities not compliant with ADWG to ensure good drinking water vary from AU$0.20 billion (median per capita water quality complaints) and AU$1.30 billion (no water quality complaints). Given that the minimum social rate of return to ensure that public project investments in Australia are economically viable is 1.065 (ref. [45]), our findings suggest a high positive social rate of return from achieving good drinking water quality for all communities across all models and all cost scenarios. Further, we estimated that the 'acceptance rates' for the proposed programme to improve water quality for all affected communities are over 50% (that is, the level that would pass a referendum). Based on the highest estimated costs of AU$1.30 billion and the proportional population subsamples, the estimated probabilities of a "Yes" vote are 69%, 71% and 58% for Models 1–3, respectively (see Supplementary Tables 19–22 for details of the calculation and results).

Enabling conditions

In addition to covering the necessary costs, Hall et al.[46] identified additional 'enabling conditions' in support of improved water supplies. These include support and appropriate technical training, cultural competence with 'authentic engagement' for delivering water supply services to Indigenous communities[47], cross-agency delivery (for example, regulation, funding, water source protection, public health and community support[46]) and avoidance of a one-size-fits-all approach to water services and instead a 'fit for place, purpose and people' approach to water service delivery[48].

Beyond enabling conditions, a systems approach for SRR communities is necessary that encompasses technological, social, cultural, governance, climatic and other factors, and all within a sufficiently and feasible time frame for delivery[49]. A systems approach was recently applied to 15 drinking water treatment plants across 14 remote island communities, with a total of 5,000 people, in the Torres Strait in the far north of Australia[50]. In this case, a pilot was co-designed among local and state-based agencies (for example, water, health, infrastructure and community relationships) to respond to multiple boil water advisories in the 14 communities, noting that some advisories were in place for more than a year[51]. In the pilot, water treatment and delivery technologies were tailored for each water source along with training for on-island operation and funding of sufficient duration to overcome the water quality and delivery deficiencies[51]. This Torres Strait pilot was a success, with respect shown for cultural practices and beliefs. Furthermore, there has been no recorded water supply contamination since its commencement[51].

Broader considerations

Using a stated preference survey, we estimated the benefits of improving drinking water in SRR communities with known drinking water quality breaches in Australia. We separately calculated the capital and operating costs to achieve good-quality drinking water in these communities and highlighted the enabling conditions to ensure long-term and culturally appropriate improvements in water services to deliver 'water for all' in Australia (Fig. 3). We also provide estimates of the range of possible net benefits when responding to non-compliance with drinking water quality guidelines in Australian SRR communities. That is, our findings quantify the aggregate WTP to improve drinking water quality in all 395 non-compliant Australian communities and the associated capital and operating costs of such improvements. By estimating the benefits, costs and enabling conditions to ensure that drinking water meets drinking water guidelines, we have provided a robust framework for prioritizing and investing in the delivery of 'water for all'.

Our results show that there is a high household WTP, including among those households that already have good-quality drinking water, for improvements to the provision of drinking water in Australian drinking water quality non-compliant SRR communities. The high WTP is consistent with other studies measuring the value of providing safe and affordable drinking water either for private benefit (the participants' benefit) or as a public good. For example, a study in the Canadian province of Alberta found that residents in affected communities would be willing to pay Can$90.20 yr^{-1} (equivalent to AU$114.94 yr^{-1} in 2022 Australian dollars) for 10 years for a 50% reduction in boil water advisories across small communities (under 500 people)[26]. Among participants who viewed their vote as consequential, the WTP rose to Can$117.60 yr^{-1} for 10 years.

A cross-sectional study involving ten OECD (Organisation for Economic Co-operation and Development) countries found that respondents who were dissatisfied with their current water quality were willing to increase their water bill by 7.5% to have their tap water quality improved[52]. Across the pooled sample, the increase in the annual water bill per household was equal to €7.8 (equivalent to AU$16.10 in 2022 Australian dollars). Studies in low-income countries have also found welfare gains from water quality improvements. For example, a home disinfection system proposed to Kenyan households attracted an average WTP of US$17 to US$77 (2015 US dollars)[23]. A 2004 study of rural-poor households in South Africa also found that respondents supported programmes to improve various aspects of water supply, with higher preferences given to improvements in quality and mode of supply (from communal bores to piped tap connections at home)[53].

Our results are of global interest given that SDG target 6.1, to "achieve universal and equitable access to safe and affordable drinking water for all" by 2030, will not be delivered to 100% of residents in either the Global South or the Global North[54]. Our estimated aggregate WTP in Australia to deliver 'water for all' and the associated capital and operating costs suggests that investments to deliver SDG target 6.1 have a high social rate of return. This is consistent with a high benefit/cost ratio from public health investments to deliver safe and affordable drinking water in the Global South[53,55].

We acknowledge that since 2018–2019, efforts have been made by government instrumentalities to improve water services in SRR communities in Australia. Notwithstanding these ongoing investments, progress has been gradual and uneven. Our results suggest that there is a robust social and economic justification for public investments to achieve universal good-quality drinking water in Australia. Our methods and findings are particularly relevant for other Global North countries that have rural and remote communities that lack adequate water services, such as the United States and Canada.

Methods

Gaps in 'good-quality' water provision in Australia

Our survey instrument was designed to understand preferences and attitudes towards water-related issues in Australia with respect to the provision of good-quality drinking water. The ADWG are the national framework for the management and regulation of drinking water supplies and include values for water quality characteristics "to ensure good quality water – that is, water that is aesthetically pleasing and safe, and that can be used without detriment to fixtures and fittings"[13]. A single exceedance of health-based guidelines is considered a non-compliance; aesthetic characteristics are assessed as an annual average[3].

Following the most recent estimates of drinking water service gaps in Australia[3], we defined good-quality drinking water as compliance with all ADWG health-based guideline values and six key physical characteristics (true colour, turbidity, hardness, total dissolved solids, pH and dissolved oxygen). In 2018–2019, the SRR Australian Drinking Water Quality dataset (Supplementary Appendix D) identified some 260,000 people (about 1% of the Australian population) living across 395 small towns and communities (under 10,000 residents) in Australia where the water supply systems were tested and failed to meet the 'good quality' definition at least once[3].

Experimental design and WTP estimation

Our survey instrument (Supplementary Appendix E) followed conventional stated preference survey design[28,56] and consisted of three main sections. The first asked participants about their perceptions and personal situation regarding water supply and other environmental and public policy issues in Australia. The second section presented information regarding the lack of good-quality drinking water in remote and rural Australian communities and asked participants how they would vote ('Yes' or 'No') for a proposed programme to improve the water quality in these communities. Participants were also asked whether they believed that their votes in the survey would have an influence on the implementation of the proposed programme and the associated tax rise. The third section included socio-demographic questions, such as postcode, education level and occupation.

The choice tasks used in this study were a stated preference valuation method where participants were asked to make a choice (typically a binary choice) for a proposed intervention, given a set price[24]. In our study, the policy intervention was the improvement in water services to ensure 'good-quality' drinking water. This was defined as the percentage of people (25%, 50% and 100%) whose drinking water supply would be improved relative to the 260,000 who were known to be exposed to substandard drinking water in 2018–2019.

An annual household tax increase to be paid for 10 years was proposed to pay for the improved drinking quality programme. The questionnaire highlighted that the proposed tax increase would be entirely dedicated to the proposed policy intervention and that it would not receive a further reallocation of existing tax expenditures. An annual household tax increase was selected as the most realistic payment

vehicle[24], noting that its acceptability was confirmed with focus groups before the survey. By comparison, an increase in water rates would not have been an appropriate payment vehicle in the questionnaire because some Australians do not pay water bills directly, for example, in rental properties[57].

Four tax rise levels (AU$50, AU$200, AU$500 or AU$1,000) and three possible levels of water quality improvement (25%, 50% and 100% of the affected communities) were randomly assigned across survey participants to test for 'scope sensitivity'. An example of the choice task is presented in Supplementary Fig. 4. Each participant responded to two independent choice tasks with varying levels of water quality improvement and household tax rises. Randomization of the choice tasks resulted in population subsamples that were statistically equivalent for each combination of tax and improvement. A script was presented between the first and second choice tasks to remind survey participants that different improvement levels were being proposed because the scope of the proposed project was being evaluated at different scales. Best practices in non-market valuation[21] were followed to ensure that participants understood that the programmes were realistic and that their answers were consequential.

In economic valuation, WTP is understood as the amount of money (or equivalent) a participant would be willing to sacrifice for a change from the baseline conditions to the proposed altered conditions[58]. An individual's utility v can be written as:

$$v(Q^O, y) = v(Q^I, y - \text{WTP}) \tag{1}$$

where Q is the level of water quality provided (Q^0 is the current level and Q^1 is the level after the proposed intervention has been implemented), y is income and WTP is the economic value of the gain[24,59].

To calculate the WTP in this study, we first estimated a binary probit[60] regression model that included the participants' responses to improvements in community drinking water quality level with associated household tax increases (or bids) to pay for these improvements on the probability of a 'Yes' or 'No' vote, as per equation (2)[61]:

$$\text{Prob}(Y > 0) = f(\alpha + \beta_1 \mathbf{X} + \beta_2 B + \varepsilon) \tag{2}$$

where Y is the Yes/No vote outcome, $f()$ is the probit model, α is a constant, X is the vector of explanatory variables, B is the bid level, β_i are model coefficients and ε is an error term.

Following model estimation, mean WTP values and confidence intervals were computed using the delta method[58]. Such point estimate approaches are common for WTP estimation in binary choice stated preferences, given that it is not possible to calculate WTP for each individual participant[62]. For robustness, lower-bound mean WTP ($\overline{\text{WTP}}^l$) was estimated using non-parametric analysis, which, unlike model-based estimates, does not require distributional assumptions nor consider effects of independent variables[63]. Thus, non-parametric mean WTP was calculated on the basis of the bid levels and the rate of vote 'Yes'[62,64].

To aggregate our WTP estimates to the relevant Australian population, we accounted for the possible divergence between the sampled and the relevant total population by making an adjustment with respect to survey non-participants[36]. A low-end estimate of an aggregate WTP was obtained by assuming a zero WTP for non-participants[36]. Thus, applying the 63.8% completion rate for those sampled (Survey design), we estimated that there are 6.05 million households in Australia, for aggregation purposes, who would be willing to pay for the proposed programme. To aggregate WTP estimates for Model 2, only 66.8% of the sample perceived the payment as consequential; thus, we applied a further proportional reduction and estimated that there are only 4.04 million households in Australia, for aggregation purposes, who would be willing to pay for the proposed programme. Likewise, we reduced the number of willing-to-pay households in Model 3 to 3.62 million to

equal the proportion of respondents in the subsample who agreed or strongly agreed to the statement "If the Australian Government implements the drinking water program: I believe my household will have to pay a tax increase to pay for the program" and indicated they had "considered the tax".

Survey design

This research was conducted under the Australian National University Ethics protocol number 2021/197 and University of Alberta Research Ethics protocol number Pro00120044. The proposed programme and the questionnaire design were tested in three rounds of focus groups. These focus groups were undertaken in Perth, Western Australia, between July 2021 and February 2022. Each focus group consisted of 8–12 individuals with diverse socio-demographic characteristics randomly selected from an opt-in pool of participants supplied by Pureprofile (www.pureprofile.com); one of Australia's largest panel providers.

Following pre-testing of the survey questionnaire in the focus groups, the online survey was administered through Pureprofile. The survey was made available to all eligible participants who self-selected to participate. Given that the proposed payment vehicle was a household tax increase, only Australian residents for taxation purposes were included as participants. Our definition of 'Australian residents for taxation purposes' was aligned with that of the Australian Taxation Office, which requires all residents in this category to file an annual tax return[37]. To ensure representativeness, response quotas for gender, age group and location were defined for the sample.

Four rounds of pilot surveys ($n = 511$) were undertaken between May 2022 and July 2022. The pilot surveys resulted in a high prevalence of 'Yes' votes, which prompted the upward adjustment of the bid levels to a maximum of AU$1,000. Adjustments in the proposed improvement levels (25%, 50% and 100%) were also made to increase the statistical power of the models. A log of survey versions is presented in Supplementary Table 9. The results of the pilot surveys were used to inform the final design (version 5), which was used in this study.

A total of 6,322 people started the survey, with 4,034 qualified completes, including pilot data (63.8% completion rate). The final version of the survey (n = 3,523) was administered in August 2022. Given that each participant responded to two choice tasks, the number of total observations was 7,046.

Limitations

Our study does not account for the costs and benefits of improved services in locations where monitoring or reporting gaps prevent assessments of access to good-quality water. This includes over 500 SRR communities[14] in the Northern Territory, regional towns in the most populous state of New South Wales, and towns or communities across Australia where service providers are not required to report water quality data[3]. Thus, establishing a standardized national drinking water database should be a policy priority for Australia[3]. In addition to actual community water quality data, such a database should include both capital and operating cost expenditures to improve water quality and water quality monitoring and reporting. With greater spatial coverage and improved water quality reporting, future estimates of the benefits and costs of ensuring good-quality drinking water, and decision-making, should improve.

We highlight that our benefit estimates account for multiple benefits (that is, WTP), including 'non-use' benefits[30] among those not affected by the interventions and benefits to SRR community residents, who were part of our sample. Other direct and indirect benefits of good-quality water to residents of the 395 SRR communities were not separately estimated. These benefits may include reduced avoidance costs (the extra cost of alternative sources, such as bottled water), improved labour productivity, greater well-being (physical and mental health) and lower healthcare costs[65].

Data availability

Data can be shared upon request by contacting the corresponding author. Further analysis is ongoing and the full dataset will be made publicly available on completion of the research project by the end of 2025.

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Author contributions

A.M., S.A., W.A. and R.Q.G. designed the WTP study. A.M. and S.A. designed the WTP survey instrument with assistance from A.S.-C., W.A., K.S.T. and R.Q.G. A.M. and S.A. conducted the formal WTP analyses. S.A. and W.A. provided expert guidance and reviewed the WTP analyses. A.S.C. assisted with the study design and WTP analyses. A.M. and R.Q.G. wrote the original draft of the paper. P.J.C., P.W. and J.H. collected or compiled the cost data. P.J.C., R.Q.G., P.W. and J.H. conducted the cost analyses and wrote the associated sections. P.W. collected and analysed drinking water quality data. N.L., S.C. and R.Q.G. wrote the Enabling conditions section. S.C. provided cultural guidance. S.F. prepared Fig. 3. R.Q.G. conceptualized, supervised, convened and coordinated the study. All authors commented on, reviewed or contributed to writing the final version of the paper.

Competing interests

The authors declare no competing interests.

Additional information

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Correspondence and requests for materials should be addressed to R. Quentin Grafton.

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