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ORIGINAL ARTICLE

Estimating non-market values of protecting groundwater in a constrained environment

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Abstract
In groundwater-constrained areas, reallocating groundwater away from agriculture to achieve environmental outcomes has become a popular top-down regulatory approach. However, little attention has been paid to understanding public preferences for such policies. Using a choice experiment, we explore community preferences for different components of a groundwater allocation management program affecting agriculture in a severely water-constrained but highly groundwater-dependent environment, Western Australia. We find strong community preferences for a substantial reallocation away from agriculture, with compensation based on ecological benefits, regular monitoring through meters and a medium-level penalty for those that over-extract. The estimated non-market value to implement a groundwater management program comprising the preferred structure is up to AU$61 million per year. This result demonstrates the value of considering community preferences when designing groundwater management policies.

KEYWORDS
Australia, environmental benefits, Gnangara, groundwater management policy, groundwater-dependent ecosystems, non-market valuation, willingness to pay

JEL CLASSIFICATION
Q25, Q28, Q51

1 | INTRODUCTION

In arid and semi-arid regions, including Australia and the United States, groundwater is a key natural resource supporting both human activity and groundwater-dependent ecosystems (GDEs). Due to over-extraction and climate change, groundwater has, however, become depleted in many areas (Famiglietti, 2014; Mulligan et al., 2014). This has led to falling water table levels, which in turn have caused significant damage to GDEs (Aeschbach-Hertig & Gleeson, 2012; de Graaf et al., 2017; Zektser et al., 2005). Recovering water for the environment to protect GDEs has therefore increasingly been embedded in groundwater management policies in medium- to high-income countries (Rohde et al., 2017).

Agriculture is one of the largest users of groundwater, and a common policy approach to returning water to the environment is to reduce the allocation to this sector (Siebert et al., 2010). This can be achieved through top-down regulatory policies (e.g., imposing allocation limits on irrigators and investing in water-saving infrastructure), economic instruments (e.g., water pricing and taxes), or bottom-up voluntary policies (e.g., water markets and buyback auctions; Guilfoos et al., 2016). To manage groundwater cost-effectively, it is necessary to implement policies that balance the economic losses from reduced agricultural water use against the environmental gains. Only by assigning a monetary value to environmental benefits can we compare these gains with agricultural losses.

The loss from agricultural water users associated with groundwater management policies can be estimated via traditional economic optimisation and farm production models (e.g. Gao et al. (2013); Iftekhar and Fogarty (2017); Pfeiffer and Lin (2012)). Monetising the environmental benefits associated with a water management policy change is, however, complex. To estimate environmental benefits, it requires the following: (i) measures of physical change in the environmental conditions associated with each policy; and (ii) a monetised unit value or function for the environmental impacts (Baker & Ruting, 2014). The physical change requirement of the estimation process is usually empirically measured or modelled by ecologists and hydrologists. Economists then use this information in hydro-economic models that link changes in hydrological conditions to changes in the dependent ecosystem via linear or non-linear functions (e.g., Esteban and Dinar (2012); Ghadimi and Ketabchi (2019); Kahil et al. (2015); Kuwayama and Brozović (2013); Lan et al. (2021a, 2021b)). In general, there are no established markets for environmental goods and services. As such, the monetised unit value for changes in environmental outcomes is often estimated using non-market valuation (NMV) techniques. Unfortunately, the monetary values used in hydro-economic studies often do not reflect the ecological response to hydrological conditions associated with management policy changes. Rather, the values used are often derived from generic NMV studies that focus on estimating society's willingness to pay (WTP) for general improvements to public goods (e.g., wetlands, parks and lakes). This disconnect could potentially bias the modelling results. For example, to assess alternative adaptation policies for drought in south-eastern Spain basins, Kahil et al. (2015) used the economic value of a wetland derived from a recreation value study and a non-recreation value study in their hydro-economic model. The authors found that the extent of ecosystem value differences across methods was large enough to alter policy recommendations, and so as part of the study the need for the accurate valuation of ecosystem services was highlighted. Faced with similar issues, Gutiérrez-Martín et al. (2020) suggest that conducting environmental valuation studies for specific policy scenarios is what is needed.

To estimate monetary values for returning groundwater to the environment, most studies have used stated preference techniques such as the contingent valuation (CV) methods or discrete choice experiments (DCE). Appendix S1 provides a review of existing key CV and DCE studies that are relevant to estimating non-market values for the environmental benefits associated with groundwater management programs. We identify three gaps in this literature, and we address them in this paper.

The first gap relates to the description of the water management scenarios. In the majority of published studies, the groundwater management scenario and the subsequent improvements to the dependent ecosystem were described ambiguously. Two studies provided specific groundwater management scenarios (Koundouri et al., 2012; White et al., 2001), and only Rinaudo and Aulong (2014) explicitly described scenarios and their associated environmental benefits. To obtain reliable NMV estimates, it is necessary to provide survey participants with specific information about the management scenarios as this ensures that all respondents understand and value the same good (Brouwer, 2008; Carson et al., 2001). Furthermore, Alpizar et al. (2001) found that respondents are often not familiar with the attributes presented in choice experiments. Groundwater is not visible to the general population. The general population is therefore likely to have only a limited understanding of groundwater, and a lack of familiarity with attributes may be a material issue for groundwater studies (Price, 1996). Presenting vague and general information may therefore result in inaccurate estimates of the WTP for the environmental benefits of different groundwater management programs (Rinaudo & Aulong, 2014).

The second gap involves the estimation and presentation of WTP estimates. There are only two CV studies (Martínez-Paz & Perni, 2011; Wei et al., 2007) and one DCE study (Mortazavi et al., 2019) that have presented WTP estimates per unit volume of groundwater (cubic meter). The remaining studies provide either a total WTP estimate for a region or WTP per household per year, and such information has only limited usefulness in direct applications of hydro-economic models and policy settings. For example, if a groundwater management program is implemented, changes in the physical groundwater conditions (water table level, quantity and quality) need to be measured. Assigning a monetary value to environmental benefits per unit of change in the groundwater level is then necessary for the estimation of costs and benefits of such a change. Volume-based estimates are therefore more useful for both hydrological modellers and policymakers.

Non-market valuation studies of groundwater management options often assess public preferences for alternative solutions to a groundwater problem and/or alternative attributes related to groundwater quantity, quality, and the dependent environment (Birol et al., 2006; Dobbie, 2013; Khan & Zhao, 2019; Kountouris et al., 2014; Smyth et al., 2009; Tempesta & Vecchiato, 2013). However, to the best of our knowledge, no prior study has provided a comprehensive assessment of public preferences across the multiple design features required in a groundwater management policy—including preferences related to regulation, financial incentives for compensation, monitoring and penalties. Understanding individuals' perceptions of different management aspects is important to the design of a policy so that it suits taxpayers' expectations and thus increases the likelihood of policy effectiveness (Anderson, 2014). An examination of these preferences is the third knowledge gap we address.

To address the gaps in the literature identified, we use the DCE method to estimate the non-market value of the environmental benefits associated with a unit of change in groundwater conditions (water table level and volume). We provide precise information to respondents. Specifically, in the description of the groundwater management scenarios, we present respondents with proposed solutions for managing declining groundwater; the subsequent improvement in groundwater level conditions; and the impact on the GDEs. The approach is similar to Rinaudo and Aulong (2014), where the CV method was used and the context was groundwater quality. We also explicitly investigate public preferences for different management program features.

This study has been contextualised for the management of the Gnangara groundwater system (GGS), the most important groundwater system in Western Australia (WA). By providing reliable estimates of groundwater-environmental benefits, and by providing an assessment of public preferences for the multiple components that constitute a groundwater management policy, the results from this study may serve as a reference for sustainable groundwater resource management beyond the specific case study context.

The remainder of the paper is organised as follows. Section 2 describes the context of the study region. Section 3 explains the data collection process and methods used. Results are presented in section 4, and section 5 provides a discussion and conclusion.

2 | CONTEXT OF THE STUDY REGION

The GGS is the largest source of low-cost good-quality water in Perth, the capital of WA. The system stretches over 2200 square kilometres along the Swan River, east to the Darling Scarp (Figure 1). The GGS consists of three main aquifers, a shallow unconfined superficial aquifer (Gnangara Mound), two deep aquifers, the semi-confined Leederville aquifer and the confined Yarragadee aquifer. Each aquifer provides groundwater for different purposes. The two deep aquifers mostly provide water for the public's scheme water supply (DWER, 2017). About 40% of the annual abstraction is used for Perth's public water scheme. Another 23% is used for agriculture and horticulture. Other uses include parks, gardens and recreation, schools, industry and households that extract water from private bores (DWER, 2022). In addition, there are 69,000 hectares of native woodlands and more than 2000 hectares of wetlands that depend on the GGS (Ranjan et al., 2009).

Due to a sustained reduction in rainfall in the region and ongoing groundwater extraction, the GGS is out of balance. Iftekhar and Fogarty (2017) estimated that the GGS water table has

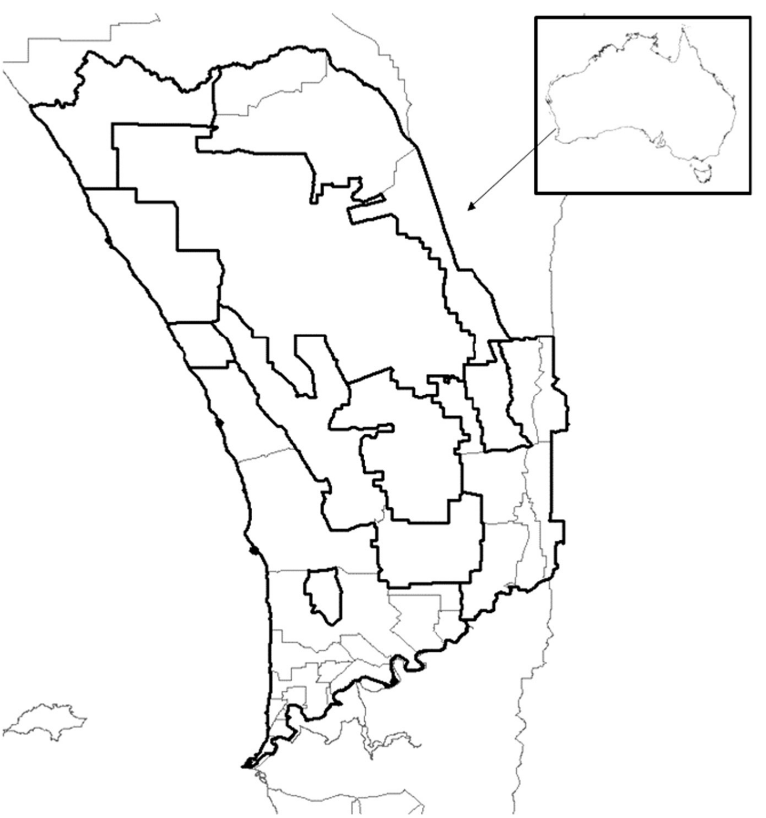

FIGURE 1 Location of the Gnangara groundwater system.

been falling by six centimetres annually, for over 35 years. The decline in the GGS water table has led to serious damage to GDEs in the region (Syme & Nancarrow, 2011). For example, a wide variety of vegetation species, including Banksia woodlands, a native WA species, have disappeared due to the fall in the water table (Groom et al., 2008). At the same time, many groundwater-dependent wetlands now rely on artificial water supplementation for maintenance (Ali et al., 2012; Environmental Protection Authority, 2007; Froend et al., 2004).

To rebalance the groundwater system, and prevent further damage to GDEs, in 2009 the WA Department of Water and Environmental Regulation (DWER), the water management authority, issued the Gnangara groundwater allocation plan. The plan was substantially updated in 2022. Potential strategies for rebalancing the system include reducing groundwater abstraction; land-use changes to increase the recharge rate; investments to improve water use efficiency; making use of water-sensitive urban design elements; seeking fit-for-purpose water supply alternatives; and investments in further research. The most recent plan indicates that to improve groundwater levels in critical areas and protect environmental and resource values it will be necessary to reduce the total annual abstraction rate by 19 per cent or 54 gigalitres (GL) per year over the next decade. In terms of individual sectors, the plan suggests that the allocation for public water supply be reduced by 27% (30 GL/year); and for the agriculture and horticulture sector, that allocations be reduced by 10 per cent (5.1 GL/year). These targets have been set based on extensive groundwater modelling (DWER, 2022).

Despite the extensive water balance modelling that has been undertaken, the extent to which social preferences, or non-market values, have been considered in setting the water extraction reduction targets is not clear. Without proper consideration of social preferences, a command-and-control regulatory strategy may face barriers to implementation due to opposition from local agricultural water users, key industries (e.g., vegetables) and local government stakeholders who might be afraid of adverse financial and economic impacts on individual farmers and the broader community (City of Wanneroo, 2019). This paper focuses on the DWER strategy of 'reduction of groundwater abstraction' with a specific focus on the agricultural sector.

Several studies have investigated the economic loss to the agricultural sector associated with reduced groundwater abstraction from the GGS (Gao et al., 2013; Iftekhar & Fogarty, 2017; Lan et al., 2021b). However, little attention has been paid to monetising the environmental benefits that would flow from reduced agricultural abstraction. Ecologists have measured ecosystem changes resulting from hydrological changes to identify the impact of groundwater depletion on GDEs but have not looked at monetary values (Froend & Sommer, 2010; Groom et al., 2008; Sommer & Froend, 2011). As such we argue that the major constraints to the quantification of environmental benefits is the lack of relevant NMVs to monetise the environmental impacts associated with changes in the hydrological condition in the region. NMV studies do exist for wetlands and parks in the region (Perriam et al., 2008; Tapsuwan et al., 2009), but the values in these studies cannot be used directly because they do not link to a unit of change in groundwater to environmental impacts (Lan et al., 2021b). Providing a monetary value for such impacts would facilitate the estimation of environmental benefits associated with groundwater management policy options and so be useful.

The existing literature has highlighted the importance of public compliance and support for environmental policies to be effective (Anderson, 2014; Lane-Miller et al., 2013; Lukasiewicz & Dare, 2016). Furthermore, individuals may be willing to make a financial contribution to establish new institutions, rules and regulations to tackle the depletion of a common pool resource such as groundwater (Agrawal, 2003; Ostrom, 1990). Such contributions can help ease the financial burden on the water management authority and on users due to reduced extraction. It is therefore valuable to understand how the public, including locally impacted communities, perceive, respond and may be willing to pay for different water management policy design features.

3 | METHODOLOGY

3.1 | Attribute selection and survey design

The selection of attributes for a hypothetical groundwater management program was established based on an extensive literature review, and also a review of government policy documents. As part of the design process, the survey and choice attributes were provided to DWER for comments. Due to the COVID-19 pandemic, it was not possible to organise face-to-face focus group discussions. A such, two rounds of online pilot testing with 142 respondents were implemented. The pilot testing was used to adjust attribute levels and establish how to optimise the way information was presented to maximise respondent understanding. Results from the pilot testing were also used as priors to generate an efficient design for the final survey. Based on the pilot testing, six attributes were selected for the main survey: (i) reduction in the total current groundwater allocation to agriculture; (ii) regulations on how to implement each reduction at the irrigator level; (iii) financial compensation to irrigators for reduced allocations; (iv) monitoring of extraction behaviour; (v) penalties for irrigator over-extraction; and (vi) cost to households for implementing the program.[1]

The main attribute of interest is the reduction in the total groundwater allocation to agriculture. Four potential levels of reduction were considered: 0%, 10%, 20% and 30%. To emphasise the environmental benefits of reductions in groundwater use, information on ecological impact was provided, based on existing ecological (Sommer & Froend, 2011) and hydro-economic (Lan et al., 2021b; Ranjan et al., 2009) studies. The beneficial impacts on wetlands and terrestrial vegetation were highlighted, as they are the two most commong GDEs in WA.

To obtain impact estimates, first, we applied the reduction in total groundwater allocation to agriculture to the hydrological model developed in Lan et al. (2021a). This allowed us to estimate the annual impact of each reduction level on hydrological conditions, expressed in groundwater table height. Next, to establish the linkage between the groundwater table height at each allocation reduction level and the associated impacts on vegetation and wetlands, we used information on the ecological response to water table height from; Ranjan et al. (2009) and Sommer and Froend (2011). Details of this relationship are presented in Appendix S2. For the other five attributes, levels were identified based on current and recommended water policies for the case study region. Table 1 presents the levels for each attribute. The description of attributes and associated levels was presented graphically to respondents. Details that show the process are presented in Appendix S3.

The levels of the attribute 'Regulation of how to implement the reduction of groundwater allocation' were selected based on a review of actual water policies. The first level, uniform reduction, is commonly used due to its ease of implementation (Tisdell, 2010). This approach has been used to reduce groundwater allocations in Nebraska, USA (Upper Republican Natural Resources District, 2019; Young et al., 2021), and in Spain (Blanco-Gutiérrez et al., 2011). The second level, a reduction in groundwater allocation proportional to ecological impact, was developed based on theoretical and empirical studies on groundwater spatial externalities (Brozović et al., 2010; Lan et al., 2021b; Pfeiffer & Lin, 2012). These studies concluded that the impact of groundwater extraction is stronger on users who live closer to the extraction point. Within the context of this study, this level of regulation means reducing the groundwater allocation by a greater amount for users who live closer to a GDE, since their water extraction impacts GDEs more heavily. The third level is a buyback auction. This approach has been implemented in the United States (Garrick

[1]Other attributes may be relevant including sectoral (agriculture, industry, public and mining) water allocation reduction.

TABLE 1 Attributes and levels used in the choice experiment.

Attributes	Status quo level	Possible levels in hypothetical groundwater management program
Reduction in total current groundwater (GW) allocation to agriculture	0% 6 cm decline in GW table; 10% vegetation loss and wetlands dry in 17 years	10% reduction: corresponds to 5.5 cm decline in GW table; 9% vegetation loss and wetlands dry in 18 years; 20% reduction: corresponds to 3 cm decline in GW table; 5% vegetation loss and wetlands dry in 34 years; 30% reduction: corresponds to 0 cm decline in GW table; and no impacts on GDEs
Regulation on how to implement this reduction at irrigators' level	None	Uniform; Proportionate to ecological impacts; Voluntary reduction through a buyback auction
Financial compensation for irrigators with reduced allocation	None	None; Equal compensation; Based on ecological impacts; Based on competitive buyback auction
Monitoring of extraction behaviour	None	None; Once a year inspection; Twice a year inspection; Meter installation for regular inspection
Penalties of over-extraction	None	None; Same as current water price; Double; Triple
Cost (one-off monetary contribution)	$0	$50; $100; $150; $200; $300; $400

Abbreviation: GDE, groundwater-dependent ecosystem.

et al., 2009; Ghosh et al., 2014) and Australia (Adamson & Loch, 2018; Crase et al., 2012; Lan et al., 2021a; Wheeler et al., 2013).

The attribute 'financial compensation for irrigators' has four levels. The levels are as follows: (i) no compensation; (ii) equal compensation where irrigators receive a homogeneous payment per kL of groundwater; (iii) proportional compensation based on ecological impacts, where irrigators whose groundwater extraction has a greater impact on the GDE receive higher compensation per kL of groundwater reduced; and (iv) compensation based on a competitive groundwater buyback auction where irrigators get compensated the amount that they bid, if they win the auction.

Both benchmark and stricter levels of the monitoring attribute were selected based on the current policy and proposals that have been discussed as relevant to the study area. For example, DWER has required extraction meters to be installed since 2020, for all licences with an annual water entitlement above 10,000 kL (DWER, 2018).

For the penalty attribute levels, we used the market price of water as the lightest penalty, relative to the status quo (no penalty). The second level of penalty is double the current market price of water, and the third level is triple the current price of water.

The cost attribute was presented in the survey as a one-off payment charged to the annual water service bill. The survey informed respondents that each management program would involve different costs and multiple funding sources, such as general taxes and charges. The levels of the cost attribute were initially based on the estimated environmental cost per kL of water, as estimated in Lan et al. (2021b), and were finalised based on the results of the two pilot tests. Table 2 presents an example choice set.

The choice experiments were designed based on the S-efficiency criterion (Scarpa & Rose, 2008), and the Ngene software was used (Rose & Bliemer, 2012). The criteria used allow the estimation of separate models for sub-samples (e.g., residents living in and outside of the Gnangara region), if required. Specific choice sets were designed to exclude any infeasible combinations of attributes and attribute levels. The design included a total of 48 choice scenarios, which were divided into six blocks of eight choice sets. Blocks were randomly allocated to respondents. Each choice set had three unlabelled options (1, 2 and 3) where option 1 was the status quo with 0% reduction in allocation, no management for all other attributes and zero cost. The other two options presented a hypothetical groundwater management program with different levels of reduction in allocation in combination with the levels of other attributes, at a cost to the respondent. A professional survey company was hired to program and distribute the survey online. The survey company was asked to provide at least 1000 completed responses from WA residents of age 18 years and older. The company was also asked to select respondents in such a way that the sample was representative of the WA population in terms of age, gender and income distribution. Additionally, the survey was also targeted such that at least 20% of respondents were from the Gnangara groundwater region. The sample characteristics are therefore slightly different from the overall WA population, but relevant to the research questions considered.

We obtained 1074 completed surveys in 2020. Table 3 provides a summary of selected socio-demographic characteristics of respondents in the sample and the WA population. The percentage of males and females and the median age in our sample are relatively close to the census data for the WA population. However, the respondents in our sample tend to have both a higher level of education and higher incomes, relative to the census data. This might be because we excluded respondents under 18 years old in our sample while the education and the median income of the WA population were estimated for all individuals above 14 years of age. Information on additional socio-demographic characteristics is presented in Appendix S4.

The survey comprised four sections. The first section introduced the survey. It also provided a video that explained groundwater and the link to GDEs. The video was 1.46 minutes in length and was developed by the New South Wales Department of Planning

TABLE 2 Example of a choice set presented in the survey.

Features	Option 1 (Status quo)	Option 2	Option 3
Reducing groundwater allocation for agriculture	0% reduction	20% reduction	30% reduction
Regulation on how to implement the reduction	N/A	Uniform	Proportionate to ecological damage
Financial compensation for affected irrigators		Equal compensation	Based on competitive buyback auction
Monitoring extraction behaviours		Once a year inspection	Twice a year inspection
Penalty of over-extraction (based on the current water price, \$2.66/kL)		Double	Triple
Cost to you (one-off)	\$0	\$50	\$250
Your most preferred option	☐	☐	☐
Your least preferred option	☐	☐	☐

TABLE 3 Socio-demographic characteristics.

Variable	Description	Sample	WA population
Number of individuals	Total number of respondents	1074	2,621,509[a]
Male	Gender (% males)	43.6%	49.9%
Age	Median age	37.9	39.4
Income	Median income (AU$)	$ 93,909[b]	$ 51,450
University degree	Education (% with university degree or higher)	39.9%	14.8%

Abbreviation: WA, Western Australia.

[a]Total number of households in WA in 2016 was 1,073,723 households.

[b]Median value is calculated using cumulative frequency of grouped income.

and Environment. The video explained graphically, what groundwater is, and the impact of groundwater depletion on dependent ecosystems. The main aim of the video was to provide respondents with an overview of groundwater and GDEs. Respondents were also asked about their familiarity with GDEs. The second section of the survey described the groundwater situation in the study area and introduced several groundwater management programs, including buyback auctions. Respondents then gave their opinion on the prevention of groundwater depletion and GDE protection. The survey also asked respondents about their awareness of groundwater depletion and groundwater management programs. The third section of the survey presented and explained all attributes and possible attribute levels in a hypothetical groundwater management program using non-technical terms and was accompanied by images.

The levels of the attribute ‘Reducing the total groundwater allocation for agriculture’ were presented with the corresponding outcomes in groundwater levels and GDEs, specifically wetlands and vegetation. Respondents then answered eight choice questions, where they selected the most preferred groundwater management program among the three options. The last part of the survey included a set of debriefing questions about respondents' uncertainty in answering the questions, and questions related to groundwater access as well as socio-demographic characteristics. For respondents who had chosen the status quo as the most preferred option in all eight choice questions, a follow-up question was asked to identify protesters' responses. Protester responses include the respondents who did not think that they should be charged for compensating irrigators; or felt that it was not fair to reduce groundwater allocations for irrigators; or those who did not want to choose between given options. About 4% of respondents were classified as protesters and were excluded from the analysis.

3.2 | Model specifications

The random utility theory model proposed by McFadden (1974) is the basis for analysing choice experiments. This approach assumes that an individual will select the alternative with the highest utility from a given set of options. In this study, respondent n is presented with choice set S, and so the utility U that respondent n receives from selecting groundwater management program i denoted U_{nsi}, can be described as:

$$U_{nsi} = V_{nsi} + \varepsilon_{nsi}, \tag{1}$$

where V_{nsi} is a systematic and deterministic component and ε_{nsi} is a random component. In Equation (1), V_{nsi} captures the impact of observable attributes of the water management program and the respondent, and ε_{nsi} captures all unobservable factors that affect utility. The probability that respondent n chooses alternative i in the choice set S is then:

$$P_{nsi} = \Pr\left(U_{nsi} > U_{nsj}\right) = \Pr\left(V_{nsi} + \varepsilon_{nsi} > V_{nsj} + \varepsilon_{nsj}\right); \forall j \neq i \text{ and } i, j \in S \quad (2)$$

The utility function of a respondent in our study is specified as a function of the cost of the program, c_{nij}, allocation reduction attributes, w_{nij}, other non-monetary attributes of the program, x_{nij}, and an alternative-specific constant, represented by a dummy variable ASC_{nij}. To identify sources of heterogeneity, we also include respondent-specific socio-economic and attitudinal characteristics as covariates (Birol et al., 2006). Four different types of variables, (i) socio-demographic conditions of the respondents; (ii) knowledge and experience related to groundwater, GDEs and groundwater management programs; (iii) attitudes related to protection and management of groundwater; and (iv) survey response behaviour, have been included as covariates in the latent class model. Multicollinearity of these variables was tested through exploratory conditional logit models before including them in the latent class models.[2] Except for allocation reduction attribute,[3] we let all other attributes enter as categorical variables, and they were dummy coded.

The attribute 'allocation reduction', w_{nij}, was treated as a continuous variable, and we included an additional square term of this attribute $\left(w_{nij}^2\right)$ to capture potential non-linear effects. Several choice experiment studies have included the square term in a continuous attribute, which generates a quadratic utility function to capture the non-linearity (Grilli et al., 2018; Zabala et al., 2021). We assumed that there is a non-linear relationship between WTP and water reduction allocation. People might be willing to pay to reduce water allocation to irrigators, but they might not want to reduce too much as it would affect irrigators' livelihood and consequently cause an upward spike in the price of agricultural products. In fact, this comment was made during the pilot survey when we asked respondents to share their thoughts about the survey. In addition, social preferences for goods and services are not always linear but can have a concave form (Zabala et al., 2021).

In our design, the 'current situation' does not reflect a situation where no option is selected, but rather a case where there is a clearly defined groundwater management scenario (i.e., no allocation reduction) where all the attributes in the choice set are at their base levels. It may be the case that respondents bring additional, unobserved perceptions about groundwater management options that are not captured by the attributes as described. We allow for this by including an alternative-specific constant (ASC) defined as equal to one for an alternative. The alternative-specific constant variable takes a value of '1' if the option is an alternative situation, otherwise '0'. This variable captures the marginal utility that individuals may hold for a groundwater management option, above and beyond the utility that is associated with the levels of the attributes that comprise that option. This variable can also control for individual's bias towards or against status quo.

Although the conditional logit model is commonly used in the analysis of multi-attribute choices, it assumes that there is no preference heterogeneity across respondents. In reality, people may have different preferences, and thus models that accommodate variation in preferences across individuals are increasingly preferred. Here, the latent class analysis technique is used to identify latent classes or groups of respondents based on their preference similarity and socio-demographic characteristics (Iftekhar et al., 2022). Specifically, a scale-extended latent

[2]To test for multicollinearity, the following steps were used. (1) Create interaction variables between the ASC dummy variable and the socio-economic and attitudinal characteristics variables; (2) run conditional logit models where the attributes, the ASC dummy variables and the interaction variables are included; and (3) calculate uncentered variance inflation factors to test for the presence of multicollinearity.

[3]We also ran separate models where we treated the allocation reduction attribute as a categorical variable. However, as our objective was to quantify the value per unit of water extraction reduced, we present the continuous variable results only.

class analysis technique is used to avoid potential confounding of preference heterogeneity with heterogeneity in error variances (Magidson et al., 2020). See Train (2009) and Hess and Train (2017) for a formulation of the model.

In a latent class analysis, parameters are estimated for different levels of individual attributes for individual preference classes (k). Based on the estimated parameters, the WTP estimates can be calculated as the ratio of the coefficients for specific attributes (β_k^{att}) and the cost parameter (β_k^{cost}) multiplied by negative 1 for a given class k, that is,

$$MWT_k^{att} = -1 \times \beta_k^{att} / \beta_k^{cost} \tag{3}$$

To find the most appropriate model, the standard practice is to run a series of models with a different number of preference and scale classes and select the model with the lowest Bayesian information criterion (BIC) and consistent Akaike information criterion (CAIC) as the most preferred model. Latent GOLD® Choice 5.1 Syntax was used to estimate the models (Vermunt & Magidson, 2013) and identify the most preferred model.

3.3 | Estimating non-market values of environmental benefits of groundwater

We are interested in two non-market values of environmental benefits per unit of change in groundwater conditions. The first is the value per unit change in the groundwater volume, which is estimated based on the WTP for the allocation reduction attribute derived from the latent class model described in the previous section.

The second is the monetary value of environmental benefits per unit change in groundwater table height, something that has not previously been reported in the groundwater literature. To estimate this value, we repeated the latent class model exercises and calculated the WTP similar to the previous model. However, in the second model, we replaced the attribute allocation reduction by its impact on the water table that was described to respondents in the survey. The modelling exercise in Lan et al. (2021b) showed that groundwater allocation reduction has a non-linear effect on the groundwater table. The marginal impact of the allocation reduction is large at the beginning and gradually drops with greater allocation reductions. It should be noted that the ecological responses are dependent on water table height, not water volume. The change in water table height not only depends on water volume of the aquifer, but also on the hydrological characteristics of the aquifer (e.g., storativity and transmissivity) and the rainfall recharge. It is therefore not accurate to simply convert environmental benefits per volume reduction to per unit of water table height.

All other attributes and interactions with the status quo remain unchanged. The WTP result for a unit change in water table derived from this model reflects the non-market value of environmental benefits per unit (cm) of groundwater table height. This WTP is reported in the result section and is used to calculate an aggregated value estimate.

Aggregation of non-market values at a population level requires us to make an assumption related to the scale of aggregation of relevant stakeholders. An analysis of the respondent's postcode data provides some idea about the potential scale of the aggregation based on their distance from the GGS. The 95th percentile of distance is 293 km, and there are 568,795 households in the postcodes within this distance. The annual environmental benefits per unit of change (i.e., \$/cm/Household/year and \$/kL/Household/year) in groundwater are then multiplied by the total number of relevant households within this distance to derive the aggregate value estimates.

4 | RESULTS

We begin this section by presenting the econometric results of the latent class model where we provide an assessment of respondents' preferences for different attributes in the proposed hypothetical groundwater management scenarios. This is followed by the results of household's WTP for different features of the program. Finally, we calculate the NMV of environmental benefits per unit of change in groundwater conditions. We also provide the household-level and aggregate-level WTP for different scenarios of groundwater management, to demonstrate the distribution of values.

4.1 | Analysis of respondents' preferences

To elicit respondents' preferences, the class structure that best fits the survey data needs to be determined in advance. Several models with the number of preference classes ranging from 1 to 6 and with one- and two-scale classes were estimated (see Appendices S5 and S6). Both BIC and CAIC statistics indicated that the SALC model with three-preference and two-scale classes was the most appropriate fit, and results for this specification are shown in Table 4.

Respondents' preferences are heterogeneous. Class 1 constitutes 42% of the respondents. This group has strong positive preferences for agriculture water allocation reductions and negative significant preferences for the squared term. The significant negative effect of the squared term indicates that the preference is relatively lower for a higher level of reduction.

There is no statistically significant difference between buyback regulation versus uniform reduction in groundwater allocation. However, this group prefers reductions in groundwater allocations proportionate to ecological damage. Regarding financial compensation for affected irrigators, all three alternatives, equal compensation, compensation based on ecological impact, and compensation based on buyback, were more preferred than no compensation. Compensation based on ecological impact was the preferred option among the alternatives.

Among the different options for monitoring, 'meter installation' was the most preferred option. This group also preferred a strict penalty, as indicated by the pattern of increasing coefficient values associated with higher levels of the penalty. As expected, the cost attribute is negative and statistically significant. The alternative-specific constant is positive and significant, indicating positive preferences of the members of this class for stricter groundwater management options.

Members of Class 2 constitute 34% of the sample. Similar to Class 1, they also have positive preferences for groundwater allocation reductions and negative preferences for the squared term of groundwater allocation reduction. However, the coefficients are not statistically significant. Members of this class also have higher preferences for allocation reductions proportionate to ecological damage, as well as compensation based on ecological impacts. Meter installation is their most preferred monitoring option. In contrast to the Class 1 members, this group has stronger preferences for moderate levels of penalty (i.e., penalty set at double the current water price). They also have strong negative preferences for the cost attribute and positive preferences for stricter groundwater management options.

Members of Class 3 (24% of the final sample) did not respond to any of the attributes except for the cost attribute and compensation based on ecological impact. This suggests that they would like to avoid spending money on alternative groundwater management options unless the option includes compensation based on ecological impact.

TABLE 4 Results of the latent class model.

	Class 1 (42%[a])			Class 2 (34%)			Class 3 (24%)		
	Estimate	Sig.	SE	Estimate	Sig.	SE	Estimate	Sig.	SE
Allocation reduction	0.145	***	0.044	0.361		0.221	0.086		0.122
Allocation reduction square	−0.002	**	0.001	−0.005		0.005	−0.001		0.003
Regulation (Base = Buyback)									
Regulation: uniform	0.124		0.125	1.009	**	0.512	0.197		0.363
Regulation: proportionate	0.294	**	0.140	3.418	***	0.945	−0.314		0.370
Compensation (Base = No compensation)									
Compensation: equal	0.473	***	0.161	0.938	*	0.547	0.326		0.474
Compensation: based on ecological impact	0.881	***	0.186	2.189	***	0.693	1.045	*	0.473
Compensation: buyback	0.356	**	0.164	−0.161		0.603	0.085		0.466
Monitoring (Base = No monitoring)									
Monitoring: once	0.915	***	0.285	7.959	***	1.932	−0.017		0.487
Monitoring: twice	1.289	***	0.293	7.085	***	1.748	0.240		0.502
Monitoring: meters	2.073	***	0.336	9.867	***	2.158	−0.980		0.620
Penalty (Base = No penalty)									
Penalty: same as the current price of water	0.304		0.253	2.645	**	1.093	−0.286		0.550
Penalty: double the current price of water	0.566	**	0.266	2.955	***	1.100	0.645		0.412
Penalty: triple the current price of water	0.683	***	0.150	−0.424		0.555	−0.231		0.347
Alternative-specific Constant (ASC)	24.595	***	5.487	23.572	***	5.347	−1.115		1.254
Cost	−0.004	***	0.001	−0.099	**	0.019	−0.032	***	0.005

Abbreviation: SE, standard error.

[a]The respective coefficients (SE) for individual classes are Class 1: 0.4167 (0.022); Class 2: 0.3448 (0.0227); and Class 3: 0.2384 (0.0127).

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

4.2 | Preference class membership

Given that we are interested in knowing what type of people have positive preferences for groundwater management, we examine the role of covariates describing class membership (Table 5). All four types of covariates, socio-demographic conditions, knowledge and experience, attitude and survey response behaviour, have a role in explaining the membership.

Members of Class 1 have strong positive preferences for groundwater allocation reductions. It seems respondents that are older in age are more likely to be a member of this class. Those who have heard the term 'groundwater-dependent ecosystem' and were aware that groundwater is depleting before the survey are more likely to belong to this class. They are also more likely to agree that groundwater should be managed primarily for environmental reasons. They also think that it was fair to ask irrigators to give up water use rights. On the other hand, they agree that everyone should contribute equally to manage groundwater and are supportive of the idea of increasing the tax for the protection of GDEs. Respondents that did not consider their financial circumstances are also more likely to be a member of this class.

TABLE 5 Preference class membership.

Characteristics	Class 1 Estimate	Class 1 Sig.	Class 1 SE	Class 2 Estimate	Class 2 Sig.	Class 2 SE	Class 3 Estimate	Class 3 Sig.	Class 3 SE	Wald	Overall Sig.
Constant	0.375		0.300	−0.553		0.338	0.178		0.283	2.780	
Socio-demographic											
Male	−0.035		0.116	−0.388	***	0.117	0.423	***	0.117	16.033	***
Under 46 years old	−0.230	*	0.124	−0.009		0.124	0.239	*	0.128	4.557	*
Residence in Gnangara area	−0.141		0.141	−0.137		0.140	0.279	**	0.134	4.292	
Have university or higher degree	0.108		0.118	−0.176		0.119	0.068		0.119	2.239	
Gross annual household income (before tax) under 69 K	0.114		0.126	−0.144		0.128	0.030		0.128	1.429	
Member of an environmental conservation group	0.276		0.205	0.254		0.212	−0.530	**	0.258	4.242	
Impacted by COVID	−0.118		0.123	−0.030		0.124	0.148		0.122	1.641	
Have access to bore water on private property	−0.019		0.137	−0.153		0.143	0.172		0.142	1.716	
Have a groundwater extraction licence	0.248		0.356	−0.617		0.435	0.370		0.353	2.063	
Knowledge and experience											
Heard the term 'Groundwater-dependent ecosystem (GDEs)' prior to the survey	0.330	**	0.132	−0.342	**	0.143	0.012		0.142	8.182	**
Know that there are specific GDE sites such as wetlands, lakes, springs, woodland/vegetation and caves in their local area (within 10 min driving distance from their house)	−0.151		0.122	−0.047		0.123	0.198		0.122	2.877	
Have visited a GDE site	0.138		0.129	0.290	**	0.130	−0.428	***	0.136	10.328	***
Heard of water buyback auction	0.013		0.162	0.252		0.171	−0.265		0.187	2.629	
Knew about groundwater reduction program	0.009		0.240	−0.515	*	0.277	0.505	*	0.290	3.967	
Aware that groundwater is depleting	0.361	***	0.124	−0.185		0.123	−0.176		0.122	8.456	**

TABLE 5 (Continued)

Characteristics	Class 1 Estimate	Sig.	SE	Class 2 Estimate	Sig.	SE	Class 3 Estimate	Sig.	SE	Wald	Overall Sig.
Attitude											
Agree/strongly agree that groundwater should be protected primarily for economic reasons	−0.246	*	0.131	−0.105		0.132	0.351	***	0.133	7.347	**
Agree/strongly agree that groundwater should be protected primarily for environmental reasons	0.303	*	0.159	−0.059		0.152	−0.244		0.151	4.157	
Agree/strongly agree that groundwater should be protected for both economic and environmental reasons	−0.109		0.143	0.279	*	0.148	−0.170		0.146	3.602	
Agree/strongly agree that protecting GDEs is important for themselves	−0.025		0.134	0.270	**	0.136	−0.245	*	0.141	4.560	*
Agree/strongly agree that protecting GDEs is important for the environment	0.226		0.221	0.015		0.221	−0.241		0.204	1.691	
Agree/strongly agree that protecting GDEs is important for the community	−0.182		0.207	−0.002		0.210	0.183		0.199	1.104	
Agree/strongly agree for increasing tax to protect GDEs	0.289	**	0.132	−0.040		0.132	−0.249	*	0.132	5.621	*
Willing to donate regularly to an environmental fund to protect GDEs instead of paying higher water bills and taxes	0.170		0.146	−0.395	**	0.161	0.224		0.157	6.037	**
Agree/strongly agree that everyone should contribute equally to protect the environment	0.262	**	0.127	−0.204		0.128	−0.058		0.130	4.723	*
Think it is fair to ask irrigators to give up water use rights to protect the environment	0.463	***	0.122	0.416	***	0.122	−0.879	***	0.125	49.900	***

(Continues)

TABLE 5 (Continued)

Characteristics	Class 1			Class 2			Class 3				
	Estimate	Sig.	SE	Estimate	Sig.	SE	Estimate	Sig.	SE	Wald	Overall Sig.
Survey response behaviour											
Confused with the choice sets	0.051		0.138	0.039		0.137	−0.089		0.142	0.399	
Considered financial situation	−1.207	***	0.158	1.073	***	0.218	0.134		0.174	58.379	***
Level of agreement with how likely the survey results will influence future policy decisions regarding groundwater management[a]	0.014		0.029	−0.004		0.030	−0.010		0.030	0.234	

Abbreviation: SE, standard error.

[a]A 10-point Likert scale from 1 = very unlikely to 10 = very likely.

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

Members of Class 2 also have positive preferences for groundwater management programs. Respondents who are female, had not heard the term GDE before the survey, did not visit a GDE and did not know about the groundwater reduction program are more likely to be a member of this class. They are more likely to agree that protecting GDE is important for them. However, they are not willing to donate to an environmental fund, and do not think that it is fair to ask irrigators to give up water use. Respondents who considered their financial circumstances are more likely to be a member of this class.

Members of Class 3 do not have any strong preferences for groundwater management. Respondents who are male and of a younger age are more likely to be a member of this class. Those who had not heard the term GDE, did not visit a GDE site and do not agree that protecting GDE is important to them are more likely to belong to this class. They are less likely to be a member of an environmental group and agree that groundwater should be protected for primarily economic reasons. Finally, the respondents who live in the Gnangara region are more likely to be a of member this class. The preferences of these respondents may, in part, be explained by the fear of losing access to groundwater if a conservation management program is implemented.

4.3 | Estimation of willingness to pay

The WTP estimates for different attributes are presented in Table 6. We first discuss class-specific WTP estimates, followed by weighted average WTP information.

Members of Class 1 have an average WTP of \$39.42 per household[4] (combining the linear and squared effects) for a 1% increase in the reduction of agricultural groundwater allocations. Relative to a buyback option, the average WTPs for the uniform and proportional options are \$33.99 per household and \$80.84 per household, respectively. Among the compensation levels, the members have the highest WTP (\$242.33 per household) for a compensation scheme based on ecological impact. All levels of monitoring attributes were valued highly by the members of this class, compared with 'no monitoring'. The mean WTP for meter installation was \$570.32 per household. They were willing to pay a maximum of about \$188 for implementing the highest level of penalty.

Compared with Class 1 members, members of Class 2 have a much lower WTP for groundwater management programs. For example, the average WTP is \$ 3.62 per household for a 1% increase in the reduction of agricultural groundwater allocations. Relative to a buyback option, the WTP for the proportional allocation cut is \$34.68 per household. Among the compensation options, the members of this class have the highest WTP (\$22.21 per household) for a compensation scheme based on ecological impact. Among the monitoring options, the average WTP is highest for the meter installation option (\$100.13 per household). Regarding the financial penalty, members of this class have stronger preferences for a lower penalty, but the average WTPs only varied from \$26.84 to \$29.99, depending on if the penalty rate is set at the market price or double the market price, respectively. Members of Class 3 do not have strong preferences for any attributes except for compensation based on ecological impact, and they are willing to pay \$32.21 per household.

Based on the WTP estimates for individual classes, it is possible to calculate the weighted WTP for the respondents in the final sample. The average WTP for a 1% reduction in groundwater allocations for agriculture is \$18.42 per household; a reduction scheme proportionate to ecological impact is \$43.42 per household; and a compensation scheme proportionate to ecological impact is \$117.06 per household. Meter-based monitoring is the most preferred option

[4]All values are reported in AUD 2020.

TABLE 6 Marginal WTP (once-off) for attributes of groundwater management program.

	Class 1 (42%)		Class 2 (34%)		Class 3 (24%)		
	Estimate	**95% CI**	**Estimate**	**95% CI**	**Estimate**	**95% CI**	**Average WTP**
Allocation reduction	40.02	[10.81, 69.23]	3.66	[−0.80, 8.13]	2.66	[−4.55, 9.87]	18.69
Allocation reduction square	−0.59	[−1.25, 0.06]	−0.05	[−0.15, 0.06]	−0.03	[−0.21, 0.15]	−0.27
Regulation (Base = Buyback)							
Regulation: uniform	33.99	[−30.29, 98.26]	10.24	[−0.51, 20.98]	6.05	[−15.92, 28.03]	19.21
Regulation: proportionate	80.84	[7.08, 154.61]	34.68	[20.54, 48.83]	−9.69	[−31.66, 12.29]	43.42
Compensation (Base = No compensation)							
Compensation: equal	130.27	[46.19, 214.35]	9.52	[−1.92, 20.96]	10.04	[−17.84, 37.92]	60.36
Compensation: based on ecological impact	242.33	[138.89, 345.77]	22.21	[7.81, 36.60]	32.21	[4.66, 59.77]	117.06
Compensation: buyback	97.95	[10.42, 185.48]	−1.63	[−13.52, 10.26]	2.61	[−25.41, 30.62]	41.21
Monitoring (Base = No monitoring)							
Monitoring: once	251.85	[59.44, 444.27]	80.76	[62.89, 98.63]	−0.51	[−29.93, 28.91]	133.11
Monitoring: twice	354.75	[137.28, 572.23]	71.89	[52.37, 91.41]	7.40	[−22.81, 37.62]	175.22
Monitoring: meters	570.32	[281.12, 859.53]	100.13	[77.89, 122.37]	−30.21	[−68.94, 8.52]	266.33
Penalty (Base = No penalty)							
Penalty: same as the current price of water	83.66	[−46.67, 213.99]	26.84	[5.49, 48.19]	−8.80	[−41.45, 23.85]	42.15
Penalty: double the current price of water	155.85	[13.88, 297.81]	29.99	[12.55, 47.43]	19.87	[−6.02, 45.75]	80.42
Penalty: triple the current price of water	188.00	[77.73, 298.27]	−4.30	[−15.25, 6.65]	−7.13	[−27.63, 13.37]	75.79
Alternative-specific Constant (ASC)	6768.20	[3472.79, 10063.61]	239.20	[187.89, 290.51]	−34.37	[−110.40, 41.66]	2915.72

Abbreviations: 95% CI, 95% confidence intervals; WTP, willingness to pay.

($266.33 per household). Finally, the average WTP for implementing a medium level of penalty was $80.42 per household.

4.4 | Derivation of per unit value of groundwater and aggregation estimation

Table 6 provides the calculation of the non-market values of environmental benefits per unit of groundwater change. As mentioned previously, two values were estimated: the first is per unit of change in groundwater volume and the second is per unit of change in groundwater table height.

The WTP for a 1% increase in the allocation reduction is used to estimate the environmental value per unit of change in groundwater volume. The value reported in Table 6 is $18.42. Since this is a one-off WTP per household, we annualised this value using a formula for calculating the perpetuity where the present value of a perpetuity (one-off WTP) equals to the ratio of annual WTP and the discount rate. The annual WTP is then estimated by multiplying the one-off WTP by the discount rate. We used a 3% discount rate, and this has also been the value used in relevant studies for the same region (Lan et al., 2021b; Ranjan et al., 2009) to get the annualised value of $0.55/household/percentage point increase in allocation reduction/year. The annual value per household is then aggregated for the relevant distance to Gnangara to obtain the annual aggregate value of $301,743/percentage point/year (i.e., 568,795 households × 0.96[5] × $0.55). To obtain the value in volumetric term, we need to divide the annual non-market value by the total volume of groundwater saved. A one per cent reduction in the annual groundwater allocation will save about 600,000 kL per year. Therefore, the aggregate non-market value of the environmental benefits of saving per kL of groundwater, on average, is $0.50.

The marginal WTP for preventing a drop in the water table is then used to calculate the environmental benefits of preventing a one-centimetre drop of the groundwater table. As described in the Section 3, this value is derived from the latent class model, where the impacts of groundwater allocation reductions on water table levels were modelled instead of the allocation reduction itself. Appendix S7 presents the full results of this model. The marginal WTP for preventing a one-centimetre drop in the water table was estimated to be $53 per household, after accounting for the squared term (Table S4). Summed across the relevant population, the central estimate for the environmental benefits per cm of groundwater table prevented is $950,115/centimetre/year.

Finally, to get a sense of the overall value of groundwater management programs, we consider two scenarios based on the weighted mean WTP estimates (Table 7). The first scenario combines features with minimum WTP compared with the baseline, and the second scenario comprises features that generate the maximum WTP. For both scenarios, the value of the alternative-specific constant is included, as we estimate the value of a very well-defined program (Iftekhar, Zhang, et al., 2021; Morrison et al., 2002). The average WTP to improve the current management in the first scenario is estimated at $99 per household per year. The average WTP in the second scenario is 1.13 times greater than the first scenario. If we multiply by the total number of households within the relevant distance band, the overall WTP for implementing the first scenario of groundwater management is about $54 million per year, and for the second scenario, it is about $61 million per year. These values are large enough for policymakers to take into consideration before implementing a program.

[5] 4% respondents were protest voters who were excluded from the analysis.

TABLE 7 Value of groundwater management programs ($/year).

	Description		Value ($/household/year)	
Attributes	**First scenario**	**Second scenario**	**First scenario**	**Second scenario**
Reduction in total current GW allocation to agriculture	10	30	5	10
Regulation on how to implement this reduction at irrigators' level	Uniform	Proportionate to ecological impacts	1	1
Financial compensation for irrigators with the reduced allocation	Based on competitive buyback	Based on ecological impact	1	4
Monitoring of extraction behaviour	Once a year inspection	Meters for installation	4	8
Penalties of over-extraction	Same as current water price	Double current water price	1	2
Alternative-specific constant			87	87
Average respondents' WTP for the whole program ($/household/year)			99	112
Number of households			546,043	546,043
Aggregate WTP for the whole program ($/year)			54,243,385	61,276,695

Abbreviation: WTP, willingness to pay.

5 | DISCUSSION

This paper is one of the first studies to estimate the non-market benefits of groundwater management programs. In the context of our case study, the results show that respondents were willing to pay for reducing groundwater allocations to agriculture to protect GDEs. The annual environmental benefit per unit of improvement in groundwater conditions derived from our WTP estimate is about $950,115 per additional cm of water table level prevented from falling. In volumetric terms, the average annual value is about $0.50 per kL per year.

There is no existing literature on environmental values per unit change in groundwater table height for comparison; however, several studies provide environmental values per kL of groundwater (Appendix S1). For example, Martínez-Paz and Perni (2011) reported that the estimated annual environmental value of groundwater in their study in Spain is $0.11/kL and Wei et al. (2007) reported the value at $0.12/kL in China. We found that our estimated values are consistent with values reported in these studies. In the Australian context, given that there is no similar study for comparison, we compare our values to the cost of alternative water supplies which we found relevant, such as recycled water and wastewater treatment. The average WTP for recycled water in WA is reported to be $0.11/kL (Iftekhar, Blackmore, & Fogarty, 2021). According to the Economic Regulation Authority (2009) in WA, the wastewater treatment price in WA is set, between the Water Corporation in Perth and the City of Mandurah, at $0.18/kL, which (given inflation) is equivalent to $0.22/kL in 2020. Our non-market values of environmental benefits per kL of groundwater fall within the range obtained by others for WA and may therefore be considered plausible. If the benefit transfer method was deemed appropriate, they could be used as information for input into cost–benefit analysis of different groundwater management options.

The most recent groundwater management plan has set a target to reduce current allocation to agriculture and horticulture by 10%, over the next decade (DWER, 2022). Our analysis reveals that the non-market benefits of such a policy would be quite substantial, even though not everyone will be supportive of the idea. We observed significant heterogeneity in people's preferences, but about 76% of the final sample have positive preferences for alternative groundwater management programs. These people either have prior knowledge of the decline in groundwater levels or have positive attitudes towards the protection of groundwater for the environment. This observation is consistent with many environmental valuation studies that find prior experience and higher levels of environmental awareness are significant factors in determining respondents' preference for an environmental management scenario (Hasler et al., 2005; Tempesta & Vecchiato, 2013).

This study is the first to investigate public preferences for different components of a groundwater management program. Several noteworthy results emerge from our study that could inform policy decision-making and future analysis. In particular, the issue of whether or not to compensate affected irrigators and level of compensation is a subject of active research (Pérez-Blanco & Gutiérrez-Martín, 2017; Varela-Ortega et al., 2011) and policy discussion (City of Wanneroo, 2019). Thus, gauging public preferences and their WTP for compensating irrigators provides a useful indication of the potential funding that public support could generate for a financial compensation scheme. Our study shows that even though there is heterogeneity in respondents' preferences on whether financial incentives should be used to compensate affected irrigators, overall, a majority of respondents preferred to provide compensation to affected irrigators, whether equal or based on ecological impact, compared with no compensation.

The second result relates to respondents' preferences on the monitoring attribute. We included this attribute in our choice experiment in addition to the allocation reduction attribute to reflect the reality that even though a reduction in groundwater allocation is imposed, there could still be violations without a proper monitoring system (Skurray et al., 2013). Ostrom (1990) has also indicated that monitoring is one of the eight principles for the effective governance of common pool resources. For groundwater, a good monitoring system not only provides reliable data for water management authorities to plan effectively (such as information on water movements, extraction details, and water table levels), but also helps to identify, sanction, and prevent cases of over-extraction. Our results show that monitoring by meters is most preferred by the respondents, in contrast to the current incomplete level of monitoring in many groundwater systems. Alcon et al. (2019) also highlighted society's preferences and WTP for water metering in the Litani River Basin in Lebanon. The Lebanon community gave priority to meter installation for surface and groundwater management prior to any other means of water tariffs.

Historically, lack of monitoring has led to over-allocation of groundwater in several regions of Australia (Harrington & Cook, 2014; Skurray et al., 2013). In WA, the reported data on groundwater use are considered inaccurate, given the inconsistencies in monitoring methods and the limited monitoring infrastructure (Harrington & Cook, 2014). Recognising the problem, DWER has attempted to improve the groundwater monitoring system by requiring meters to be installed for new licences. In the recent management plan, it has been suggested that all licensees in the plan area with an annual water entitlement equal to or greater than 10,000 kilolitres a year (kL/year) must meter their water use and submit metering data (DWER, 2022). However, many existing groundwater bores, including agriculture and private garden bores remain unmetered. Improving the whole monitoring system would require a substantial budget, especially for expensive modes of monitoring such as meters (Kern & Johnson, 2009). According to our survey, people are willing to pay $266, on average, to implement meters which would enable high levels of monitoring. This translates to a total of about $145 million for the total number of households within a 293 km (95 percentile) distance from Gnangara and indicates a willingness of the public to potentially subsidise a substantial expansion of water extraction metering.

Respondents in our study preferred the idea of imposing a penalty for over-extraction, providing support for 'graduated sanctions', identified by Ostrom (1990) as another design principle for common pool resources management. Even though respondents preferred regular monitoring, they were in favour of a less severe penalty. This is consistent with findings from other studies that have investigated the magnitude of penalties in governing common pool resources (Lopez, 2013; Velez et al., 2012).

6 | CONCLUSION

This paper is one of the first studies to estimate WTP for different aspects of groundwater management programs in Australia. It has found that respondents have strong preferences for not only protecting groundwater, but also for different aspects of a groundwater management program, such as monitoring and sanctions. The non-market value of the environmental benefit associated with not letting the groundwater level fall by one additional centimetre per year was estimated at about $950,000 annually, for a reference population of more than 500,000 households. For an additional kL of groundwater, the annual non-market value of environmental benefit is about $0.50.

The results also revealed that respondents did not have any strong preferences across different types of regulation, but respondents did have clear preferences on other elements of the water management strategy. Respondents preferred: a higher level of allocation reduction (>10%); that impacted farmers be compensated for any reduced water allocation; that water extraction be monitored; and that there should be penalties for over-extraction. On average, respondents supported a groundwater management program that reduces agricultural groundwater allocations so that GDEs can be maintained, and for implementing such a program, the respondents were willing to pay, on average, an amount ranging from $99 to $112 per household per year.

Other important findings from this study relate to the correlation between the choice of groundwater management program, and socio-demographic characteristics, attitudes and experience of groundwater use and GDEs. The results showed that the sub-group of respondents that are male, have access to groundwater bores and live in the Gnangara area (near the groundwater resource) did not support any of the proposed groundwater management scenarios. In contrast, greater WTP for groundwater management actions were found with respondents who had prior experience visiting GDEs and had pro-environment characteristics (e.g., were members of an environmental conservation group, or had knowledge and positive attitudes towards protecting the environment).

There are two key policy implications from these findings. First, to identify the most cost-effective management approaches, cost–benefit analysis can be used by water managers, with the non-market value of environmental benefits derived from this study used as an input to the evaluation process. Second, given the strong support from the local population for protecting GDEs by reducing agricultural water allocation, DWER can implement reductions to agricultural users of more than 10 per cent, and this action will have community support. The method used to implement the cut does not appear to matter to the general public; however, there is community support for compensating farmers, monitoring water extraction and imposing financial penalties for over-extraction.

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DATA AVAILABILITY STATEMENT

Data can be made available upon receiving reasonable request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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