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Capitalised nonmarket benefits of multifunctional water-sensitive urban infrastructure: A case of living streams

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Abstract

Living streams are an important element of decentralised stormwater management solutions. They are actively promoted due to their ability to generate multiple ecosystem services, including water quality improvement, biodiversity protection and aesthetics. However, a lack of monetised values of ecosystem services of living stream projects makes it difficult to assess the net benefits of investing in such projects. This study uses the hedonic pricing method to estimate the capitalised amenity values of living streams and other public open spaces (POS) in housing and lot markets for the first time. The study area includes two newly greenfield-developed suburbs in the Perth metropolitan area. We find the positive impact of living streams and other POS on the house and lot prices. However, living streams generate greater value than other types of POS. Furthermore, the POS (including living streams) that support active recreation are valued more than basic POS without active recreation features. Finally, we observe, for the first time, that the benefits of planned but not yet constructed POS (including living stream) are similar to the completed POS (including living stream) in both housing and lot markets. This information is useful for policymakers and developers making informed decisions about water-sensitive urban infrastructure.

KEYWORDS

Australia, living streams, nature-based solutions, public open space, water-sensitive urban designs

JEL CLASSIFICATION

Q51, Q57, R31

1 | INTRODUCTION

Many cities and towns are gradually losing their natural environment due to increased pressure from rapid population growth, unplanned development and climate change impacts. Natural waterways and public open spaces are degrading in many places, resulting in the loss of amenity values, recreational opportunities, biodiversity and other ecosystem services. Urban authorities are under increasing pressure to manage environmental degradation while meeting the demand for amenities and liveability.

Traditional urban planning and water management systems are failing to meet the twin challenges of fulfilling the ecological and social demands placed on them (Ashok et al., 2016). Consequently, there has been a growing need for more integrated planning and engineering approaches, such as water-sensitive urban design (WSUD), which were introduced in the 1990s. Water-sensitive urban design is an engineering design and land planning approach that offers an alternative to conventional stormwater management. It integrates the urban water cycle (including potable water, wastewater and stormwater) into built and natural landscapes to provide multiple benefits to society (DWER, 2017).

Implementation of WSUD projects by private developers is critically important due to shortages of suitable public land in urban areas. However, quality WSUD projects are not commonly included in private developments for various reasons, including physical and environmental characteristics of the location; lack of capacity to integrate new infrastructure; limited resources; policy ambiguity regarding environmental requirements; uncertainty in the maintenance of WSUD assets after completion of the development projects; and uncertainty about the return on investment (Fogarty et al., 2021; Furlong et al., 2019; Tjandraatmadja, 2019).

Typically, urban authorities rely on regulatory means to encourage private developers to supply environmental services. For example, in Australia, it is a common practice to require a certain percentage of new developments to be used and developed as public open spaces (POS), including local parks. Developers are also required to undertake on-site stormwater quality treatment or participate in offset programmes if there are water management issues. However, such a top-down regulatory approach may not deliver the best possible environmental, and social outcomes as private developers are often motivated to meet the development standard at minimum cost.

Financial incentives are one way to motivate developers to implement water-sensitive urban infrastructure (Buurman et al., 2021; Fogarty et al., 2021). Before making an additional investment, private developers would need to be convinced about the return on their investment (Buurman et al., 2021). For example, developers would need to understand whether or not an additional investment in 'activation' features such as walking paths, benches or playgrounds would generate an adequate return. However, even though there is information about the expected environmental benefits of WSUDs, quantified monetised information on their social and economic benefits that is suitable for business cases is lacking due to the shortage of nonmarket valuation studies (Gunawardena et al., 2020). In this paper, we contribute to this literature by estimating the implicit price (nonmarket value) of various elements of WSUD projects.

This study focusses on living streams, which are important elements of WSUD. A living stream is a constructed or retrofitted stormwater conveyance channel that mimics natural streams' characteristics, morphology, vegetation and stormwater conveyance (DWER, 2017). In addition to conveying stormwater, living streams can perform additional functions. For example, they treat stormwater through physical and biological processes, improve water quality, create diverse habitats to support the existence of a wide range of plants and animals[1]

[1]There are some evidence of biodiversity benefits of living streams. For example, according to the South East Regional Centre for Urban Landcare in Perth, Western Australia, several years after the implementation of the Bannister Creek Living Stream project, they observed recovery of habitat for a wide range of birds, return of turtles, more controlled water flow and water filtration functions (SERCUL, 2023).

and provide an amenity for the residents (Department of Environment and Swan River Trust, 2006; DoW, 2011; Ruibal-Conti et al., 2015). In spite of the expected social benefits of living stream projects, not many studies have estimated the economic value of establishing different types of living stream projects (Gunawardena et al., 2020). Without such information, it is impossible to determine whether a living stream project would generate additional benefits compared with a traditional POS and whether including active recreational features would enhance the value of a living stream project.

Given that there is no established market to assess the values of water-sensitive projects, we need to use nonmarket valuation techniques. This paper applies hedonic pricing, a commonly used revealed preference method (Champ et al., 2017). In the hedonic pricing method, residential units' price is considered an effective device for estimating the environmental nonmarket use-values. Under the assumption that the price of a composite good, such as a residential property, consists of the values of its components such as its suburb, surroundings, structural characteristics and amenities, the hedonic pricing method captures people's willingness to pay for the nonmarket value component of the property (Champ et al., 2017).

Many studies have applied hedonic analysis to estimate nonmarket values of POS and WSUD projects (Gunawardena et al., 2017). A majority of them have used the price of a house or a dwelling as the main instrument to assess the value. However, private developers are often concerned with the sale prices of both houses and residential lots. It is important for them to understand the impact of WSUD projects not only on the prices of houses but also on the prices of residential lots. Existing hedonic pricing studies have rarely focussed on the impact of WSUD projects on lots or plots. If greenfield development projects include WSUDs, the buyers could incorporate the amenity values of future WSUD projects into their current purchase decisions. However, due to a lack of studies, it is unknown whether a WSUD project could influence the price of a lot. In this paper, we contribute to addressing this knowledge gap by examining the impact of WSUD projects separately on the prices of dwellings and lots.

The main objectives of this paper are to (1) assess the nonmarket value of living stream projects in a greenfield development; (2) assess the additional benefits of 'activating' public open space and living streams; and (3) assess and compare the responses of markets for dwellings and lots to a WSUD project. This information will be useful for the more integrated implementation of WSUD projects in private developments.

2 | REVIEW OF HEDONIC PRICING STUDIES ON WSUD

Many studies have used hedonic pricing methods to estimate the nonmarket values of WSUDs. However, the results are mixed as they depend on the specific WSUD elements and project context. Some studies found a positive impact on house prices (i.e. positive nonmarket values) attributed to WSUD components. For example, a study on urban wetlands in Perth, Western Australia, found that the number/area of wetlands within 1.5 km of the property and proximity to a wetland significantly positively impacts house sales prices (Tapsuwan et al., 2009). Another study on the value of different types of wetland and wetland amenities in the Portland, Oregon, metropolitan area has also found a positive relationship (Mahan et al., 2000). They estimated that a one-acre (0.4 ha) increase in the nearest wetland size increases the nearby house value by 0.02%, while the value of a house located 1000 feet (305 m) closer to a wetland is 0.36% greater.

In Minnesota, Sander and Zhao (2015) found that the amenity of blue and green spaces positively impact house prices, especially in the wealthier part of the metropolitan areas of the Twin Cities. In China, Kong et al. (2007) found a positive amenity impact of green spaces on house prices in Jinan City. Lastly, in Perth, Western Australia, Polyakov et al. (2017) found that restoring an urban drain and converting it into a living stream has a significant 4.7% increase in the values of houses within 200 m of the living stream.

Other studies have found a negative value associated with some WSUD components. For example, Irwin et al. (2017) used housing transaction data to study the impact of stormwater retention basins on adjacent house prices in suburban Baltimore County, Maryland. They found a negative impact and estimated a decline in the value of houses closer to the basins by 13%–14%. Similarly, Netusil et al. (2014) reported a small negative impact on nearby house prices in Portland, Oregon, due to the proximity and abundance of green street facilities.

Bin (2005) conducted a study in Portland, Oregon, to determine the effects of proximity to wetlands on property values. The study indicated that only the open water type of wetlands has a significant positive association with its nearby property value among all general categories of wetlands. On the contrary, other types of wetlands, such as emergent vegetation and forested and scrub–shrub wetlands, have either a negative or an insignificant impact on house values.

Out of the studies mentioned above, only Polyakov et al. (2017) examined the nonmarket values of converting a drainage structure into a living stream. This type of restoration involves costs that need to be offset by the value generated by the restored living stream in order to become economically feasible. The study found that the living stream project was economically feasible, as the calculated benefit–cost ratios were 3.0, 2.8 and 2.6, with a real discount rate of 5%, 7% and 9%, respectively (Polyakov et al., 2017).

After reviewing the literature, we have identified three areas where our paper contributes new knowledge. First, the case study by Polyakov et al. (2017) focussed on an established suburb, and its findings might not be applicable to living streams and WSUD in greenfield developments. Greenfield developments provide more flexibility to plan and integrate WSUDs and POSs with the rest of the development, allowing for the optimisation of these systems' social and environmental services. To our knowledge, no study has yet examined the impact of living streams as part of greenfield development.

Second, existing valuation studies on different aspects of WSUDs have mostly used survey-based methods such as choice experiments (Iftekhar et al., 2018, 2021, 2022). Only a few studies have estimated the value of different designs of WSUDs using revealed preference approaches such as the hedonic price method. In this paper, we contribute to this literature by estimating the additional value derived from 'activated' POS and living streams. This allows for more refined benefit information to be used in business case development for the first time.

Finally, there is a lack of research on the impact of planned infrastructure development on house prices in the context of POS or WSUD. While there have been many studies on the effect of planned transportation infrastructure development on house prices (Bao et al., 2021; Golub et al., 2012; Knaap et al., 2001), there is a knowledge gap regarding the value of planned development of POS and WSUD. It is important to understand how much buyers can perceive and incorporate the future development of WSUD into their purchasing decisions. This information is important for urban planning purposes. Our study contributes to the literature by analysing the impact of both planned and completed POS and living streams at the time of sale on both house and lot prices for the first time.

3 | METHODOLOGY

3.1 | Study area

In Perth, Western Australia, WSUD is a critical development issue. Perth is expanding along the south-eastern and north-eastern development fronts. New construction in these development fronts has high levels of groundwater that must be protected from development side effects. According to the regulations, new structures are only permitted if they support substantial ecological functions of the available wetlands in the area (DBCA, 2014).

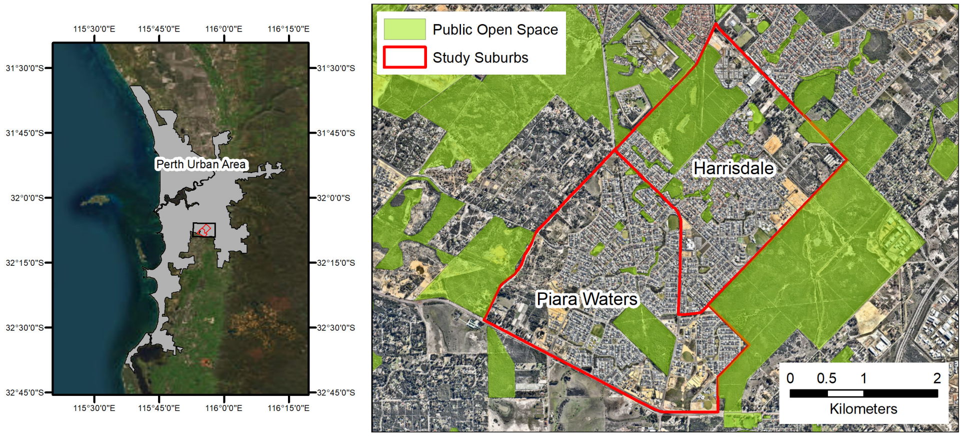

FIGURE 1 Map of the Perth urban area and the study suburbs (Piara Waters and Harrisdale). [Colour figure can be viewed at wileyonlinelibrary.com]

Additionally, according to Western Australia's existing guidelines, all developers should allocate at least 10% of the total construction area to POS to create adequate recreational opportunities for locals (DPLHWA, 2021). Due to the geomorphologic features and ecological benefits, more POS have been constructed in the form of living streams in new suburbs (Middle & Tye, 2010).

Bolleter (2018) found that the construction of living streams as part of the mandatory POS spaces in new suburbs is valued, and living streams in these areas are considered a high amenity type of POS. They suggested that in cities such as Perth, which is growing into seasonally waterlogged land, the living stream model is a good solution for dealing with complex drainage issues. In addition, Bolleter (2018) argued that it is vital to better understand the amenity that living streams can provide for the city and its residents. This paper responds to this call.

In close consultation with Western Australia's Department of Water and Environmental Regulation and Department of Planning, Lands and Heritage, two newly developed ('greenfield') suburbs, Harrisdale and Piara Waters, within the city of Armadale, were selected for this study. These suburbs are located 20 km southeast of the Perth CBD (Figure 1). When gazetted in 2007, both suburbs were covered by small farms and wetlands and had a population of several hundred people. By 2021, most of the area of these suburbs was converted to residential land use, and the population reached 26,696 people (Figure 2 and Table 1). Some parts of both suburbs are still being developed, and the population is expected to grow. Because Harrisdale and Piara Waters were developed at approximately the same time, they are similar in population density, demographics and income. However, their population density is higher, the population is younger, and household income is higher than the averages in Perth urban area (Table 1).

Harrisdale and Piara Waters are greenfield developments, which allowed the planning of a network of living streams, constructed wetlands and other types of POS. At the time of analysis, existing living streams cover approximately 35 ha of the total area of the suburbs. This is equivalent to about 4% of the total constructed land (excluding bush areas), highlighting the importance of living streams as an element of the landscape. The POS and living streams were designed at the subdivision stage, and construction of some living streams and POS began simultaneously with the development. However, sometimes houses were built before the green infrastructure was completed. The dynamics of the suburbs' development are shown in Figure 2.

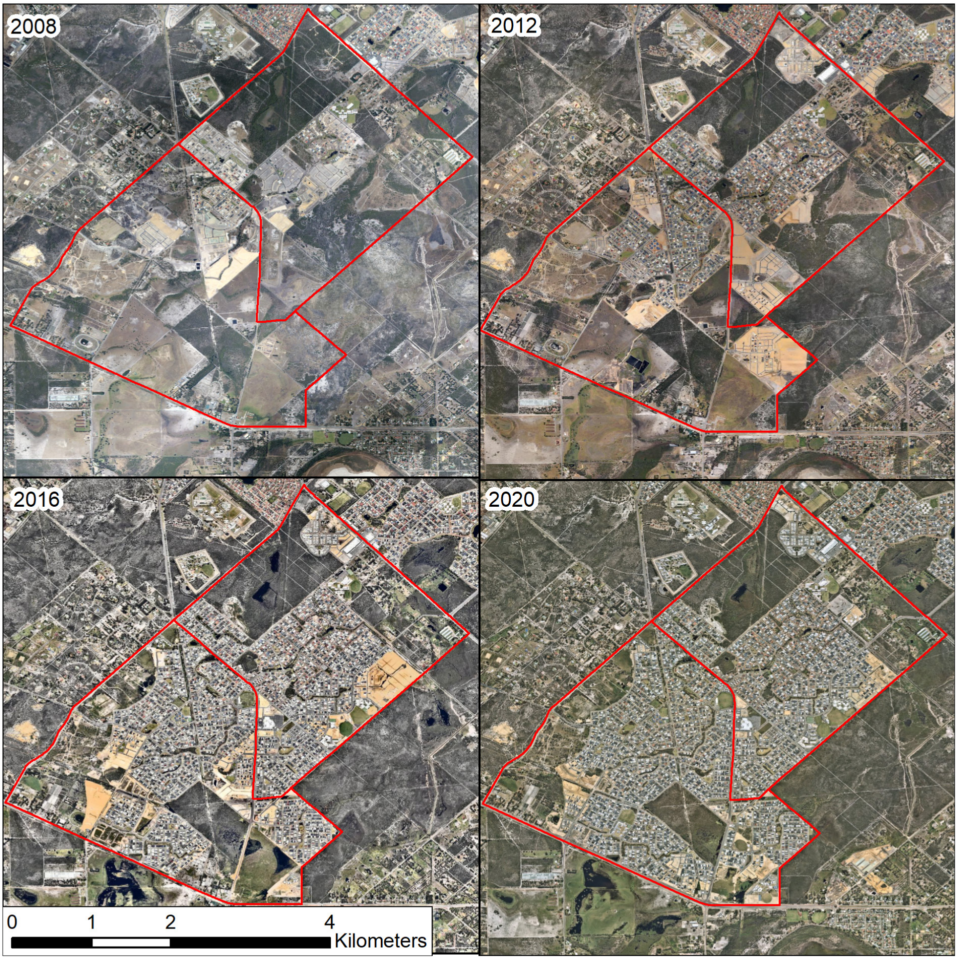

FIGURE 2 Aerial images showing the development of Piara Waters and Harrisdale suburbs from 2008 to 2020. [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Descriptive statistics of the suburbs of Piara Waters and Harrisdale and Perth urban area (ABS, 2021).

Suburb	Population (persons)	Area (ha)	Population density (persons/ha)	Median age (years)	Median household income ($/week)
Piara Waters	15,029	667	22.5	31	2477
Harrisdale	11,667	579	20.2	33	2412
Perth urban area	2,043,762	172,030	11.9	37	1863

3.2 | Hedonic pricing method

The hedonic pricing method is a revealed preference nonmarket valuation method that allows estimating values of the characteristics of market goods (Rosen, 1974). It assumes that the price of a house is determined by its features, including structural, locational and environmental characteristics. One can express house price as a function of its characteristics:

$$p_i = F(\mathbf{s}_i, \mathbf{n}_i, \mathbf{q}_i), \quad (1)$$

where p_i represents the sale price of the house i, $\mathbf{s}_i$ is a vector of house structural characteristics such as the number of bedrooms, bathrooms and size of a block, $\mathbf{n}_i$ is a vector of house locational characteristics such as the distance from the highway or the city's central business district (CBD) and $\mathbf{q}_i$ is a vector of environmental characteristics, such as distance to a local park or the park size (Freeman, 1993).

The amenity benefits of environmental assets to homeowners depend on various factors, including their extent, type, characteristics and proximity to homes. Representing both proximity and extent to value multiple types of assets using hedonic models is challenging. Different metrics have been used to achieve this goal. One common approach is to use proximity to an asset either as a discrete variable (absence–presence within a certain distance; Garrod & Willis, 1994; Polyakov et al., 2017, 2022) or as a continuous variable (linear, log or inverse distance; Daams et al., 2016; Łaszkiewicz et al., 2019, 2022; Mahmoudi et al., 2013; Tapsuwan et al., 2009; Tyrväinen & Miettinen, 2000). However, this method can be problematic when dealing with multiple heterogeneous assets (Tapsuwan & Polyakov, 2016) or when the metric of interest is the size or extent of environmental assets. Another approach is to use the gravity index (Pandit et al., 2014; Polyakov et al., 2015; Powe et al., 1997), which represents the distance and the extent of different types of environmental assets. However, the results from this approach could be challenging to interpret for policy development purposes.

A third approach is to use proportions or areas of different environmental assets, for example types of green space within a certain distance of the house (Doll et al., 2022; Kestens et al., 2004; Sander et al., 2010; Saphores & Li, 2012). This approach quantifies the impact of the extent of various kinds of greenspace. Still, it relies on the assumption that homeowners derive benefits from greenspace within a certain distance from the house. In our study, we use this approach because we are interested in obtaining policy-relevant estimates of the value of POS. These metrics are consistent with policy targets, such as the percentage of POS in a suburb or new development, while less complicated than the gravity index approach.

We choose the natural log-transformed dependent variable[2] for the interpretability of the coefficients. In this model, the coefficient of an independent variable represents the percentage change in the dependent variable for a one-unit increase in the independent variable. A coefficient for a log-transformed variable is interpreted as an elasticity. A simple functional form, such as semilog, tends to outperform more complex specifications in recovering marginal effects when the hedonic function is misspecified (Abbott & Klaiber, 2010; Cropper et al., 1988).

In hedonic models, spatial dependencies between observations are likely because of unobservable spatial factors such as proximity to major roads, schools and shopping centres and spatially correlated explanatory variables. Using ordinary least squares (OLS) in such circumstances may lead to biased parameter estimates and invalid standard errors. Commonly used approaches to deal with these issues are spatial fixed effect models, spatial heteroskedasticity and autocorrelation consistent (spatial HAC) estimators, and spatial estimators (spatial error and/or lag models). Kuminoff et al. (2010) found that spatial fixed effect models are better in alleviating omitted variables biases than spatial models. Koschinsky et al. (2012) suggest that spatial fixed effects reduce spatial correlation in errors but may not alleviate it completely.

Therefore, we use a spatial fixed effect in conjunction with spatial heteroskedasticity and autocorrelation consistent (spatial HAC) estimators. Statistical Areas Level 1 (SA1) is used as

[2]To test the decision on functional form, we used a Box–Cox transformation for the pooled model. The optimal value of lambda for the pooled model is −0.26, which is close to a function with a natural log-transformed dependent variable.

spatial fixed effects to control for omitted variables bias. Statistical Areas Level 1 is the smallest reporting unit of the Australian Census of Population and Housing, with an average population of about 400 people. In our study area, the average size of SA1 is approximately 50 ha, which is larger than the anticipated extent of the impact of living streams. After estimating a spatial fixed effect model, we test for spatial autocorrelation of the residuals and use Conley spatial HAC standard errors (Conley, 1999, 2008). In addition to spatial fixed effects, we use year-quarter temporal fixed effects to control for price trends over 14 years of the study period. We define the empirical model as follows:

$$\text{Log}\left(P_{it}\right) = \sum_{a=1}^{A} \alpha_a S_{i,a} + \boldsymbol{\beta}\mathbf{x}_i + \kappa k_{it} + \boldsymbol{\gamma_t} + \boldsymbol{\rho_i} + \varepsilon_{it}, \tag{2}$$

where P_{it} is the observed sale price of property i at time t; $S_{i,a}$ is the proportion a-th type of public open space within a buffer of property i; $\mathbf{x}_i$ is a vector of characteristics of property i ; k_{it} is the binary variable indicating whether the sale of property i at time t occurred before (0) or after (1) the construction of the nearest POS; $\boldsymbol{\gamma_t}$ is the temporal (year-quarter) fixed effects to control for dynamics of housing prices; $\boldsymbol{\rho_i}$ are SA1-level spatial fixed effects to control for spatial heterogeneity; and $\boldsymbol{\varepsilon}_{it}$ is an error term. The α, $\boldsymbol{\beta}$ and κ are parameters to be estimated.

3.3 | Data

We obtained property sales data from the commercial data provider https://www.pricefinder.com.au/. The data set contains information about home sale prices, dates and structural characteristics of each property, such as the area of the house, the number of bedrooms and the number of bathrooms. Since new construction has begun in the study area after 2007, the data on transactions are from 2007 onwards. The study area is a greenfield development, and the majority of properties were sold as lots. The data set obtained from the data provider contains sales records for 8321 lots and 2610 houses. We adjusted sales prices to the 2019 level using the Consumer Price Index. After matching data with cadastral data (spatial data set of property boundaries) and removing observations with missing data and outliers, we obtained records for 8297 lots and 2493 houses. The missing data were due to coding errors, for example 0 bedrooms, and did not show any patterns. We considered outliers observations with prices in the lower or upper 0.5% of the price range following standard practices (Ma et al., 2015). Table 2 presents a summary of the key variables in the sample.

To map the POS data in our study, we used land parcels from the cadastral map obtained from Landgate's Shared Land Information Platform (SLIP) and aerial images from the Nearmap website. Using these resources, we identified and classified POS parcels into various categories, such as living streams, parks, natural vegetation (bush) and sports grounds. In cases where a POS or type of POS occupied only a fraction of a land parcel, we split the parcel accordingly. Additionally, we recorded the POS construction dates using aerial images taken on different dates.

To distinguish between ‘activated’ and ‘nonactivated’ POS, we consulted local urban water experts (Shelley Shepherd, personal communication, October, 2019). According to their advice, we defined an ‘activated’ POS as one that supports active recreation and contains one or more of the following features: benches, barbecue places, playgrounds or exercise equipment. In contrast, a POS that did not contain any of those features was considered ‘nonactivated’. Figure 3 illustrates the location of different types of POS in the study area.

TABLE 2 Summary statistics for model variables.

Variables	Houses ($n = 2493$)				Lots ($n = 8297$)			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Sale price (2019 AU$)	595,533	135,392	162,780	1,083,612	300,887	57,757	160,824	1,044,333
Land area, m^2	491	124	195	795	440	120	193	795
Number of bedrooms	3.74	0.48	2	6				
Number of bathrooms	2.03	0.18	1	5				
Number of car parks	2.04	0.26	1	5				
Pool present	0.10	0.30	0	1				
House age (years)	4.73	2.58	1	11				
50 m buffer								
Proportion of sales after construction of POS	0.465	0.499	0.000	1.000	0.148	0.355	0.000	1.000
Proportion of activated living streams	0.029	0.077	0.000	0.476	0.032	0.083	0.000	0.627
Proportion of nonactivated living streams	0.005	0.031	0.000	0.331	0.005	0.031	0.000	0.351
Proportion of activated parks	0.015	0.049	0.000	0.395	0.014	0.049	0.000	0.603
Proportion of nonactivated parks	0.012	0.041	0.000	0.371	0.009	0.035	0.000	0.350
Proportion of bush	0.010	0.045	0.000	0.425	0.009	0.044	0.000	0.497
Proportion of sport grounds	0.001	0.011	0.000	0.195	0.002	0.015	0.000	0.331
100 m buffer								
Proportion of sales after construction of POS	0.749	0.434	0.000	1.000	0.246	0.431	0.000	1.000
Proportion of activated living streams	0.046	0.073	0.000	0.372	0.044	0.077	0.000	0.586
Proportion of nonactivated living streams	0.007	0.027	0.000	0.245	0.007	0.027	0.000	0.256
Proportion of activated parks	0.022	0.043	0.000	0.408	0.021	0.047	0.000	0.422
Proportion of nonactivated parks	0.015	0.039	0.000	0.411	0.012	0.035	0.000	0.411
Proportion of bush	0.025	0.076	0.000	0.503	0.023	0.073	0.000	0.526
Proportion of sport grounds	0.003	0.018	0.000	0.266	0.004	0.025	0.000	0.325
200 m buffer								
Proportion of sales after construction of POS	0.900	0.300	0.000	1.000	0.359	0.480	0.000	1.000

TABLE 2 (Continued)

Variables	Houses (n = 2493)				Lots (n = 8297)			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Proportion of activated living streams	0.056	0.051	0.000	0.201	0.050	0.051	0.000	0.217
Proportion of nonactivated living streams	0.008	0.019	0.000	0.114	0.009	0.021	0.000	0.133
Proportion of activated parks	0.026	0.031	0.000	0.162	0.024	0.034	0.000	0.188
Proportion of nonactivated parks	0.018	0.031	0.000	0.252	0.015	0.029	0.000	0.252
Proportion of bush	0.049	0.107	0.000	0.597	0.049	0.106	0.000	0.597
Proportion of sport grounds	0.008	0.023	0.000	0.202	0.009	0.029	0.000	0.219

To test the impacts of POS on property value at different distances, we constructed three buffers around each property parcel with widths of 50, 100 and 200 m. We then intersected the buffers with the POS layer and calculated the proportions of each POS type within each buffer. Finally, we linked the data on the proportion of POS within the three buffers and dates of POS construction with property sales records. Table 2 provides summary statistics of the explanatory variables for both houses and lots. It is worth noting that the characteristics of lots include only the area variable.

4 | RESULTS

We estimate a pooled model described in Equation (2) without and with spatial fixed effects. We checked for spatial autocorrelation on models' residuals using Moran's I (Moran, 1948) using 8-nearest neighbours spatial weight matrix. The test indicates that model residuals are spatially correlated (without spatial fixed effects: $I=0.221$, $p<0.001$; with spatial fixed effects: $I=0.158$, $p<0.001$). Spatial fixed effects reduced but did not eliminate spatial correlation. We then estimated and plotted empirical covariograms of the OLS residuals (Figure 4). An empirical covariogram is a covariance between pairs of residuals depending on the distance (lag) between observations. The plot confirms that spatial fixed effects reduced but did not eliminate spatial correlation, which remains within approximately 200 m. Therefore, our model estimates use Conley Spatial Heteroskedasticity and Autocorrelation Consistent (HAC) errors (Conley, 1999, 2008).

The two main aspects of our research are understanding the benefit of implementing water-sensitive and activated POS and whether these benefits are capitalised in both houses and lots. Therefore, we estimated regression models separately for houses (Models 1–3 in Table 3) and lots (Models 4–6 in Table 3). Within each sample, three separate models have been estimated: 50 m (Models 1 and 4, Table 3), 100 m (Models 2 and 5, Table 3) and 200 m (Models 3 and 6, Table 3) buffer sizes.

The models' results clearly show that different house and land characteristics significantly impact house or land values. For example, for a 1% increase in lot size, the price increases by about 0.5% for both houses and lots. Each house could be sold at a 9%–10% higher value with each extra bathroom, and the price of a house will be about 5%–6% higher with each additional parking space. On the contrary, the house price decreases by about 2% each year as the

FIGURE 3 Location of sales and types of public open space in the study area. [Colour figure can be viewed at wileyonlinelibrary.com]

house ages. This is consistent with the expectation that the older the house gets, it fetches a lower price. Surprisingly, the number of bedrooms has a positive but insignificant impact. This could be due to the positive correlation between lot size and the number of bedrooms. The impacts of house characteristics are similar in the three models with different buffer zones. While these variables have been included to control for idiosyncratic house and land characteristics, our main variables of interest are activated living streams and POS.

Next, we test whether the values of houses and lots differ depending on whether they were sold before or after the public open space was constructed. The coefficients of the binary variable 'Sale after POS was constructed' are not statistically significant in all models for both houses and residential lots. In other words, there is no statistically significant difference between the values of the planned but not completed POS and the value of the POS completed by the time of sale. This suggests that the buyers value future amenity of planned but not completed POS and incorporate it in their purchase decision.

Using the 50 m-distance buffer models (1 and 4), we estimate that within immediate proximity (i.e. within 50 m), a one percentage point increase in the area of the activated living stream can add 0.16% (95% CI: 0.06%–0.25%) to a house value and 0.17% (95% CI: 0.14%–0.20%) to a lot value. On the contrary, the impact of activated parks is higher on houses and lots, 0.22%

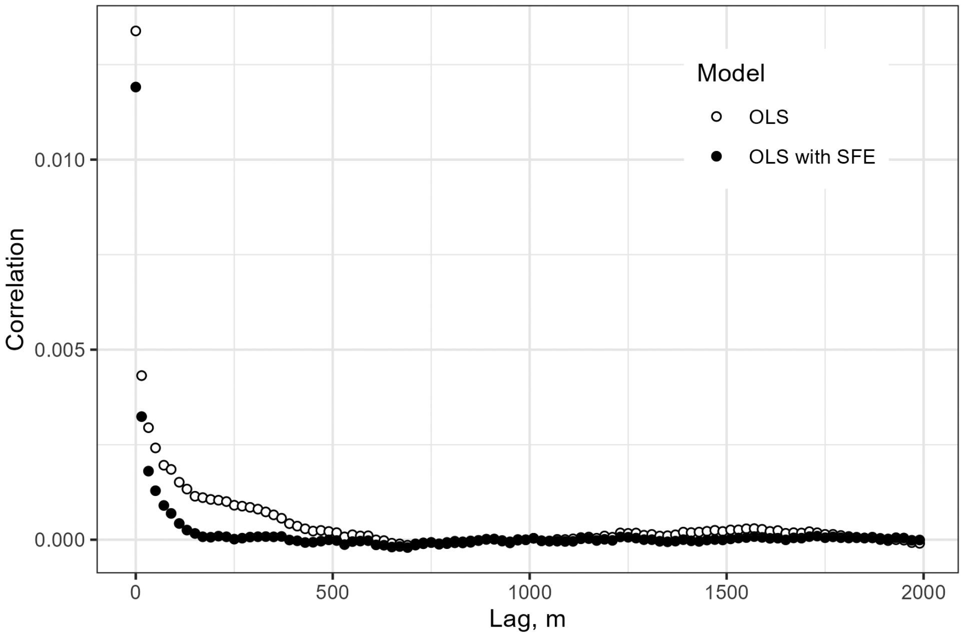

FIGURE 4 Covariograms of the residuals from the OLS and OLS with spatial fixed effects estimations of the pooled hedonic model.

(95% CI: 0.09%–0.35%) and 0.16% (95% CI: 0.09%–0.22%), respectively. The impact of sports grounds on house prices is much higher than the impact of activated living streams and activated POS, 0.62% (95% CI: 0.16%–1.08%), even though the impact on lot prices is comparable with an activated living stream or a POS.

The direction of the impact is the same when a wider buffer is considered (100 m, Models 2 and 5). By comparing the relevant coefficient values for different distance buffers, we observe that even though the impact of activated parks and sports grounds diminishes with a wider buffer, the impact of the activated living stream is higher in models with wider buffers. This gives us confidence that the amenity benefit of a living stream could be observed even at an intermediate distance (within 200 m).

Nonactivated living streams and parks show some mixed trends. The impact of nonactivated living streams on house prices becomes significant in models with wider buffers. A one percentage point increase in the area of a nonactivated living stream can increase house value by 0.06% (95% CI: −0.11%–0.23%), 0.33% (95% CI: 0.13%–0.53%) and 0.38% (95% CI: 0.04%–0.72%) for 50, 100 and 200 m distance buffers, respectively. However, the impact of nonactivated living streams on lot prices is positive but insignificant. In contrast, nonactivated parks do not influence house prices even though, with wider buffers, the impact of nonactivated parks becomes positive on lot prices. For example, for 100 and 200 m distance buffers, the impact of nonactivated parks on lot prices is 0.10% (95% CI: 0.04%–0.17%) and 0.27% (95% CI: 0.17%–0.37%), respectively.

Based on the information provided in Tables 2 and 3, we can estimate the monetary value of the benefits generated by activated and nonactivated living streams and parks. We present values for 50 and 200 m distance buffers for ease of comparison in Table 4. At first, we derive the percentage impacts on the house and lot prices (top panel). By multiplying the average proportion of activated and nonactivated living streams and parks presented in Table 2 by the respective coefficients presented in Table 3, the average percentage contribution of living streams and parks on houses and lots is calculated. Two things are noteworthy: first, the magnitude of impact is larger for models with wider buffers, and second, activated living streams have contributed more than activated parks. On average, activated

TABLE 3 Result of the estimation. Dependent variable log (property price). Conley spatial HAC standard errors.

	House			Lot		
Variables	**50 m**	**100 m**	**200 m**	**50 m**	**100 m**	**200 m**
Model	1	2	3	4	5	6
Log (Lot area)	0.464***	0.460***	0.455***	0.515***	0.508***	0.501***
	(0.029)	(0.029)	(0.029)	(0.016)	(0.016)	(0.016)
Number of bedrooms	0.011	0.009	0.008			
	(0.010)	(0.011)	(0.011)			
Number of bathrooms	0.096***	0.097***	0.101***			
	(0.017)	(0.017)	(0.018)			
Number of car parks	0.057***	0.060***	0.062***			
	(0.011)	(0.011)	(0.011)			
Pool	0.121***	0.120***	0.119***			
	(0.010)	(0.010)	(0.010)			
House age	−0.016***	−0.017***	−0.019***			
	(0.004)	(0.004)	(0.004)			
Sale after POS was constructed	0.013	−0.009	0.014	0.009	0.006	0.002
	(0.009)	(0.011)	(0.010)	(0.008)	(0.006)	(0.006)
Proportion of activated living streams	0.159***	0.241***	0.198*	0.170***	0.195***	0.301***
	(0.061)	(0.082)	(0.119)	(0.033)	(0.039)	(0.082)
Proportion of nonactivated living streams	0.063	0.333***	0.384*	0.063	0.044	0.051
	(0.102)	(0.119)	(0.219)	(0.052)	(0.082)	(0.158)
Proportion of activated parks	0.221**	0.163	−0.088	0.158***	0.085	−0.027
	(0.099)	(0.123)	(0.207)	(0.060)	(0.062)	(0.098)
Proportion of nonactivated parks	0.021	0.053	−0.248	0.023	0.101	0.271**
	(0.085)	(0.110)	(0.178)	(0.058)	(0.071)	(0.118)
Proportion of sport grounds	0.623*	0.320	0.376*	0.138*	0.164**	0.092
	(0.323)	(0.235)	(0.207)	(0.071)	(0.071)	(0.097)
Proportion of bush	−0.053	−0.007	−0.023	−0.031	−0.005	0.013
	(0.066)	(0.048)	(0.047)	(0.065)	(0.040)	(0.031)
Num.Obs.	2493	2493	2493	8297	8297	8297
R^2	0.594	0.592	0.591	0.672	0.67	0.668
AIC	−2044.2	−2034.4	−2027.2	−14546.8	−14508.5	−14465.1
Std.Errors	Conley (0.2 km)	Conley (0.2 km)	Conley (0.2 km)	Conley (0.2 km)	Conley (0.2 km)	Conley (0.2 km)
FE: SA1	X	X	X	X	X	X
FE: Year_Quarter	X	X	X	X	X	X

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

living streams have uplifted the property value by 1.11% (95% CI: 0.10%–2.12%), and for lots, the impact is 1.51% (95% CI: 1.18%–1.83%) when we consider 200 m distance buffer. By multiplying these values with the average property (dwelling and lot) prices, we can estimate the monetary values of the impacts (bottom panel, Table 4). The monetary values

TABLE 4 Capitalised values to house and lot prices.

	50 m		200 m	
	House	**Lot**	**House**	**Lot**
Percentage impact				
Activated living stream	0.46 [0.19–0.73]	0.54 [0.43–0.66]	1.11 [0.10–2.12]	1.51 [1.18–1.83]
Nonactivated living stream			0.31 [0.03–0.58]	
Activated parks	0.33 [0.13–0.53]		0.22 [0.13–0.31]	
Nonactivated parks				0.41 [0.26–0.56]
Value, AU$ per property				
Activated living stream	2746 [1121–4371]	1637 [1297–1977]	6603 [590–12,617]	4528 [3555–5501]
Nonactivated living stream			1829 [191–3430]	
Activated parks	1974 [784–3165]		666 [385–946]	
Nonactivated parks				1219 [767–1670]

are estimates in the 2019 AU$. The average contribution of an activated living stream to a house value was $6603 (95% CI: $590–$12,617), and the average contribution to a lot value was $4528 (95% CI: $3555–$5501).

5 | DISCUSSION AND CONCLUSION

Nature-based solutions or WSUD are gaining popularity as part of integrated urban water management solutions. These systems offer clear biophysical and water management benefits, even though information on their social and private benefits is lacking (Iftekhar & Pannell, 2022). To better understand the value of these systems, it is necessary to quantify the monetised value of their intangible benefits. This will help to understand the relative social preferences for different features of WSUD and incorporate such information into formal benefit–cost analysis.

Our paper contributes to four knowledge gaps in the existing literature: estimation of the nonmarket value of living stream projects in greenfield development, estimation of the additional value derived from the 'activation' of public open spaces and living streams, testing whether the impact is consistent across markets for dwellings and residential lots and testing whether there is any difference in the impacts of planned and completed POS on house and lot prices.

We have found that the nonmarket benefit of constructing living streams is positive in greenfields, which is consistent with findings for values of living streams in developed areas (Polyakov et al., 2017), even though the impact is much more nuanced than previously reported. Our analysis reveals that private nonuse benefits, such as recreation and aesthetics, are captured in the prices of houses and lots located in close proximity to the sites. There could be an element of altruistic social benefits in the capitalised value; however, it is not possible to identify it separately in our analysis.

In a greenfield setting, it appears that living streams need to be activated in order to generate significant positive benefits. The impact of nonactivated living streams was found to be low or insignificant, and in fact, an increase in the area of a nonactivated living stream could reduce prices of properties within 50 m, as suggested by the confidence interval. This indicates that the nonactivated living streams may provide private disamenity values to people living in very close proximity. It could be attributed to the fact that the nonactivated living streams provide mixed services such as habitat and flood control, which are not as clearly defined as services from recreational features.[3] On the contrary, the benefits of an activated living stream are noticed even in houses and lots located further from the sites. This suggests that there is a benefit to private developers to implement activated living streams and for governments to encourage such integrated development.

In addition, we examined whether the impact of public open spaces and living streams is consistent across two different markets: houses and residential lots. While residential lots have been used to value various amenities and infrastructure before (Barnett, 1985; Knaap et al., 2001), they have not been used to value water-sensitive urban infrastructure to our knowledge. Interestingly, the results from the residential lots market are similar to the results from the housing markets, with activated living streams having positive impacts on the lot prices and the impact persisting over longer distances. Furthermore, we tested whether anticipated values of planned but not completed living streams and other types of POS are capitalised in property values. Our findings give confidence in implementing living streams and other POS in greenfield development. Property developers are likely to capture the value of these benefits even before the houses are constructed and public open spaces are completed.

Public agencies and private developers can use the results of this study in several ways. First, this information helps understand people's relative preferences for different POS and WSUD options. Second, the implicit price estimates for different POS and WSUD options could be directly used in benefit–cost analysis and investment analysis to understand the value of establishing different types of WSUD options. Finally, it provides evidence that the investment in POS and WSUD would be captured by the developers even if the POS is not completed at the time of sell of houses or lots.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the commercial data provider https://www.pricefinder.com.au/. Restrictions apply to the availability of these data, which were used under licence for this study.

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