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Climate Change Impacts on Water Sensitive Urban Design Technologies

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Abstract: Water Sensitive Urban Design (WSUD) technologies are green infrastructures that aim to restore the hydrological balance of urban catchments. This research aimed to investigate the impacts of climate change in an infiltration-based WUSD, called soak-away, at residential allotments from a Village Green townhouse complex, Aldinga, South Australia. To do so, specific rainfall data for the study area were collected and then projected for the years 2030, 2060 and 2090, considering the RCP 4.5 and 8.5 pathways. The projections were determined using CSIRO's Climate Futures tool, as suggested in the Australia Rainfall Runoff guidelines. The rainfall's projected impacts on the soak-away performance and dimensions were analyzed in terms of the Village Green catchment conditions, using the MUSIC model and stormwater source control principles. When analyzing the RCP 8.5 pathway for different years, the distinction in soak-away design was more evident and was directly related to the peak flow percentage of the increase obtained in the MUSIC model. On the other hand, for RCP 4.5, the years 2030 and 2060 presented the same characteristics, and 2090 had an equivalent rainfall projection as RCP 8.5 2030. Regarding treatment effectiveness, the soak-away dimensions reached almost 100% of pollutant removal, which indicates that the approach might oversize the system. Nonetheless, when comparing all soak-away designs, the recommended soak-away system tends to be conservative due to the uncertainties surrounding future climate projections.

Keywords: water sensitive urban design; climate change; soak-away; infiltration system

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1. Introduction

Future climate projections indicate that there will be an increase in the frequency of extreme weather events, causing drought and flooding conditions [1]. Meanwhile, rapid urbanization further aggravates this scenario by increasing the impervious surface in urban areas [2]. Water Sensitive Urban Design (WSUD) approaches could provide a sustainable solution to assist in urban stormwater management and ease the burden of conventional drainage systems [3]. There are several types of WSUD technologies available, and the common trait among them is the principle of restoring the natural balance as far as practicable in urban scenarios [4].

According to Ahammed [3], one of the most popular infiltration-based WSUD devices in Australia is the soak-away, an underground system. This structure can contain stormwater runoff, reduce peak surface runoff and assist in the flood management of urban catchments [5]. Those benefits can have a fundamental role in building climate change resilience in populated areas [6]. To evaluate climate risks, the utilization of models can be a useful tool to assess the reliability of systems considering different future scenarios [7].

Research Background and Problem Statement

The Intergovernmental Panel on Climate Change (IPCC) has recently released its Sixth Assessment Report called 'AR6', predicting a global average warming of 1.5 °C or higher levels that will affect rainfall patterns and intensify precipitation events and associated flooding [8]. Australia is already experiencing worsening weather events because of climate change, causing environmental disasters, risking the wellbeing of the population and challenging the agriculture sector [9]. The WSUD practices have shown great potential to solve some of those problems by decentralizing the water management systems and improving a series of aspects related to water [10].

In fact, WSUD technologies may provide additional climate change resilience in terms of increasing water demands and a greater need for soil moisture retention within urban areas, which points to a necessity for further evaluation of WSUD assets in view of climate change impacts [11]. It is known that climate conditions and catchment characteristics influence the hydrologic design and, ultimately, the overall pollutant removal effectiveness of water management devices [12]. However, to the authors' knowledge, very few studies have investigated the impact of climate change on WSUD systems. Ahammed et al. [3] investigated a case of stormwater management with climate change impacts for Dhaka City and demonstrated how leaky well-based WSUDs could transform Dhaka's unsatisfactory drainage network into one that is sustainable. This research aimed to contribute to this overlooked aspect by investigating the influence of future changes in rainfall patterns on a soak-away device, considering a residential allotment at Aldinga, South Australia. According to the Council's Community Plan 2030 [13], approximately 77% of Aldinga's community is concerned with climate change impacts. The region has been suffering due to extreme rainfall patterns and long periods of drought [14]. Some studies regarding rainfall analysis have been developed for this area [15,16], but there is still a gap in knowledge involving the re-design of WSUD technologies considering the future climate. This study aimed to understand the climate change impacts on the design of a hypothetical soak-away technology installed in the area.

2. Literature Review

2.1. Climate Change Impacts in South Australia

According to IPCC [8], countries including Australia have been experiencing more frequent and heavy rainfall events since the 1950s. The Bureau of Meteorology (BoM) [17] confirms that information by stating that rainfall intensities have indeed increased in Australia, especially short-term extreme rain events, particularly in South Australia. Although heavy rains are expected to become stronger, the region is experiencing drier weather conditions, higher evapotranspiration and increases in rainfall intensity, a pattern that is likely to continue in the future [11,18].

South Australia is already witnessing more intense summer storms (flood events) and winter rainfall declines [19,20]. On top of that, bushfire risks have risen in the region and longer fire seasons are expected due to dryness, annual temperature increases and extremely hot days (>40 °C) [18]. This scenario is causing severe economic losses, mostly for the agricultural industries, and harming the well-being of the population [15]. Therefore, climate change has become an important consideration for the country's economies and sustainable development, especially considering long-term water resources management.

2.2. Future Climate Change Projections

Overall, climate change is expected to have an adverse effect on rainfall intensities for many locations in Australia. The Australian Rainfall and Runoff (ARR) is a part of the National Climate Change Adaptation Framework, which is being recognized as an important planning initiative to promote the safety and well-functioning of new and existing infrastructure [21]. Future climate tendencies are intrinsically dependent on human behaviours and, therefore, subject to a lot of uncertainties [22].

The RCP scenarios are used in global climate models (GCMs) and can range from the lowest carbon emission scenario (RCP 2.6) to the highest concentration pathway (RCP 8.5) [23]. It is worth mentioning that although RCP 8.5 is considered an 'extreme' scenario, research is labelling it as the most 'normal' or realistic future scenario [22].

2.3. WSUD Infiltration Systems

In the Australian context, three WSUD infiltration systems are frequently used: leaky wells, infiltration trenches and soak-aways [3]. Those systems can alleviate the quantity of water being directed to the conventional drainage systems by collecting stormwater runoff, storing it and slowly releasing it into the soil, not only assisting in flood management and soil irrigation but also in the removal of pollutants from the water [10,24]. Ahammed et al. [24] investigated the techno-economic analysis of WSUD technologies with conventional drainage systems for a medium catchment of South Australia and observed that the systems are techno-economically feasible. Despite its benefits, there are some constraints to infiltration systems: the structure must be placed in soils with high permeability and with a relatively low water table [3,25].

Furthermore, infiltration might also require the implementation of a pre-treatment, such as a gross pollutant trap (GPT), to remove larger solids of the stormwater runoff before it enters the infiltration system. Those systems are also known as 'sediment traps' or 'litter traps', and they will reduce the risks of clogging the infiltration device [12].

2.4. Soak-Away Device

The soak-away is an infiltration 'tank' system placed underground, which can offer great advantages by not sacrificing areas that could be destined for other purposes. These infiltration systems can be placed in highly populated areas, reducing local runoff volume and mitigating flood events [5]. The structure of the soak-away can be enveloped within a permeable geotextile to allow the gradual release of water collected from the roof and other sources to the surrounding soil [26]. To attend to a larger catchment area, the soak-away structures can be combined to increase their capability to store a bigger volume of stormwater runoff [26].

The soak-away size will depend on some factors such as the soil type of the region as well as the amount of predicted stormwater volume to be received and stored by the system [27]. As mentioned before, an important cause of failure of the soak-away is clogging, which happens when solids accumulate in between void spaces of the structure, leading it to easily overflow [28]. Another concern is the stability of nearby foundations as soak-aways tend to increase the water content in the soil, which might be dangerous in expansive soils [25]. As an example of soak-away implementation, the City of Burnside Council has recently started a project regarding the installation of infiltration systems for capturing stormwater and delivering it to young tree surroundings. Those systems were called 'B-pods', which also contributed to reducing the velocity and amount of stormwater volumes flowing to urban watercourses [29]. With the impermeabilization of the surface, projects like 'B-pods' can make a great difference, especially during drought periods or extreme weather events due to climate change impacts.

2.5. Knowledge Gap

Currently, very little academic research focuses on the design resilience of infiltration-based WSUD technologies to climate change, such as Zhang et al. [30] who investigated a constructed wetland and a biofilter system and Tirpak et al. [31] who evaluated bioretention cells. There is limited information regarding the performance of soak-away in the long term, considering climate change impacts on rainfall patterns, and this research gap is explored in the present study.

3. Methodology

Previous studies regarding WSUD systems used a variety of modelling software, such as SWIMM 5.2, DRAINS W8, MIKE 21, and MUSIC 6.3, to evaluate the infrastructure's performance under a set of different conditions [30–34]. A couple of published articles also analyzed climate change impacts on WSUDs [30,31]. However, the methodology of this study focuses on the applications of various models, such as MUSIC, source control principle, Climate Future tool and life cycle cost analysis together.

According to the ARR guidelines, the CSIRO's Climate Futures web tool provides guidance in the consensus of various Global Climate Models (GCMs) developed to predict future climatic conditions. For this reason, this decision-support tool was employed in this study to determine the projected rainfall intensity for the three future time periods (2030, 2060 and 2090) at different scenarios of greenhouse gas concentrations—RCPs, RCP 4.5 and RCP 8.5.

The City of Onkaparinga Council supplied their own approved climate dataset for use in the MUSIC model, which is the recommended source of climate data indicated by a Water Sensitive SA [11]. This climate dataset was projected and then imported to the MUSIC model for further analysis of the impacts of the projections on the peak flow and consequently, the surface runoff volume that would be directed to the soak-away system, considering the catchment area of a house allotment at Green Village, Aldinga.

Concurrently with the climate data projection, the Argue et al. [35] model was executed to determine the soak-away dimensions and emptying time for the design flows of 5-year ARI and 20-year ARI. The calculation of the soak-away dimensions also required the consultation of the 2016 IFDs dataset from the Bureau of Meteorology (BOM), which are the most current IFDs, to collect the rainfall intensities for the study area considering those average recurrence intervals and the critical storm duration for the study area (20 min).

Afterwards, the combinations of the preliminary soak-away dimensions obtained by the Argue et al. [35] model were reviewed and adjusted in view of the increase in the peak flow calculated from the results of the MUSIC model. In other words, the percentage of increase of the peak flows due to the climate change impact was 'transferred' to the Argue et al. model [35], which led to the re-dimensioning of the soak-away systems. Finally, a hydraulic and hydrological comparison between the soak-way designs was performed, considering several aspects, such as dimensions, financial costs and technical efficiency.

3.1. Study Area

The study area is situated in the Aldinga suburb of the City of Onkaparinga Council, which is the largest metropolitan council in South Australia. This area is mainly rural and an important source of water supply for Adelaide, also providing water for farming activities and for the natural environment [15]. For this study, residential allotments of the Village Green townhouse complex were selected as the study site, being located approximately 40 km from Adelaide CBD.

The site sits in the proximity of Willunga Creek (as seen in Appendix A) and is part of the Onkaparinga Water catchment and the Willunga Basin. According to Beecham and Chowdhury [16], the Onkaparinga catchment has a median annual rainfall of approximately 770 mm and an intense rainfall variability, with less rainfall during the summer and heavier rains during winter [16]. The soil's region is mainly composed of sandy and silty loam soil.

3.2. Data Collection

The Council provided a MUSIC template with the meteorological dataset from 2001 to 2010, including the evapotranspiration data relevant to the study area, which was used as the base in the data analysis process for the climate change projections. To represent the catchment area in MUSIC, the area for the source nodes was determined by utilizing the QGIS Desktop 3.20.0 'Measure Area' tool. Through that tool, it was possible to estimate roof, road, paved and pervious areas. With both that information, the areas of the source nodes and the rainfall and evapotranspiration dataset, it was possible to set the preliminary MUSIC model that was used as the base for modelling different scenarios.

The 2016 IFD relationships from the Bureau of Meteorology (BoM) website were also consulted by imputing the geographic coordinates of the Green Village house allotments. The rainfall intensity for the design flows of ARI = 1 in 5 years and ARI = 1 in 20 years were collected, considering the site's critical storm duration of 20 min. The average recurrence intervals of 5-year ARI and 20-year ARI were selected as they are commonly used as design storms in SA.

In addition, the 3 months ARI (4EY) was collected to estimate the high flow bypass value for the soak-away structure, as recommended by the Water Sensitive SA [11]. Those rainfall intensities were applied in Argue et al.'s source control principles [35] for soak-away design techniques to determine its preliminary dimensions and emptying times. The soak-away dimensions were later modified, considering MUSIC's peak flow increments, for the projected scenarios.

3.3. Data Analysis

In sequence with the collection of data, several procedures were performed which started with the definition of the climate change projections for 2030, 2060 and 2090 at 4.5 and 8.5 RCPs. Then, it was also discussed how the soak-away dimensions were determined and re-dimensioned considering the climate change projection on the rainfall data. The three main components discussed in this section are focused on the Climate Future web tool from CSIRO, MUSIC modelling and Argue's stormwater source control method.

3.4. Calibration of the IFDs Considering the Climate Change Factor

The climate change projections for the rainfall dataset collected from the City of Onkaparinga Council were estimated using the procedures set out in 'Interim Guideline for Climate Change', from ARR's book *A Guide for Flood Estimation* [36]. Firstly, the guidelines outline a six-step decision procedure to determine if climate change projections should be incorporated into the flood design [36]. It is important to highlight that this procedure is subjected to professional judgement and is up to the designer to define the climate change impacts on the asset and its consequences on the surroundings. By performing this decision-making procedure, it was concluded that, because there is no statutory requirement for the current study, a cost-effectiveness analysis would be appropriate to assist in the decision on how to proceed with the design requirements.

Secondly, the Climate Futures web tool developed by CSIRO and the Bureau of Meteorology is utilized to assist in applying the Interim Guideline. This tool can inform about the projected changes in temperature and rainfall for certain regions, based on the latest GCM and the RCPs scenarios [21]. Through this tool, it is possible to identify a 'maximum consensus' case and the resultant classification of future weather, which can include:

- Annual Mean Surface Temperature: 'slightly warmer' (<+0.5 °C), 'warmer' (+0.5 to +1.5 °C), 'hotter' (+1.5 to +3.0 °C) and 'much hotter' (>+3.0 °C).
- Annual rainfall: 'much wetter' (>+15.0%), 'wetter' (+5.0 to +15.0%), 'little change' (−5.0 to +5.0%), 'drier' (−15.0 to −5.0%) and 'much drier' (<−15.0%).

Ball et al. [21] recommend the selection of RCP 4.5 as the lowest concentration pathway and RCP 8.5 as the highest, considering the best GCM consensus GCM cases. Table 1 summarizes the projections from the Climate Futures tool for the scenarios being analyzed.

Table 1. Climate Future tool outputs.

	Year	2030	2060	2090
RCP 4.5	Consensus	43%	33%	37%
	Annual Mean Surface Temperature (°C)	Warmer (0.5 to 1.5)	Warmer (0.5 to 1.5)	Hotter (1.5 to 3.0)
	Annual rainfall (%)	Drier (−15 to −5)	Drier (−15 to −5)	Drier (−15 to −5)
RCP 8.5	Consensus	52%	38%	46%
	Annual Mean Surface Temperature (°C)	Warmer (0.5 to 1.5)	Hotter (1.5 to 3.0)	Much hotter (>3.0)
	Annual rainfall (%)	Little Change (−5 to 5)	Little Change (−5 to 5)	Much Drier (<15.0)

From Table 1, it can be noticed that in the scenarios that involve the lowest concentration pathway, RCP4.5, the consensus among the GCMs is the same ('warmer' and 'drier') for the 2030 and 2060 years of projection. In contrast, for the 2090 scenario, the temperature prediction reaches the 'hotter' condition, where temperatures may vary from 1.5 °C to 3 °C. Regarding the RCP 8.5 pathway, the predictions show great variability for the chosen scenarios, especially when considering the temperature, which seems to keep spiking over the years.

In practice, to calculate the rainfall intensity projections, Ball et al. [36] explain that, because of the uncertainties surrounding rainfall projections due to the regional variation, a 5% increase in rainfall intensity per °C is recommended. This is translated in a formula for temperature scaling, given by:

$$I_p = I_{ARR} \times 1.05^{T_m} \tag{1}$$

where:

I_p is the projected rainfall intensity (mm/h).
I_{ARR} is the current design rainfall intensity (mm/h).
T_m is the temperature at the mid-point of the class interval (°C).

3.5. Soak-Away Design

Soak-away is a small-scale stormwater management system that aims to increase the infiltration into the soil [27]. According to Ahammed et al. [24] and Argue et al. [35], the basic formula to design a soak-away is:

$$A_{soakaway} = \frac{V}{(e \times H) + (60 \times K_h \times \tau \times U)} \tag{2}$$

where:

$A_{soakaway}$ = area of soak-away;
V = critical stormwater runoff volume;
e = void space ratio: $\frac{total\ space\ available}{total\ volume\ of\ device}$;
H = height of the soak-away;
K_h = soil hydraulic conductivity;
τ = critical storm duration (tc) + site time of concentration (ts);
U = moderation factor.

3.6. MUSIC Modelling

For the MUSIC modelling, the Water Sensitive SA [4] guidance on modelling approaches was followed. According to the Water Sensitive SA [4], since pollutant concentrations may substantially differ depending on surface types, the application of the split approach on source nodes can provide a more accurate modelling. Therefore, to determine the existing runoff conditions of the study area, the split surface type approach was undertaken, which mainly involved:

- Splitting the house allotments by surface types (e.g., roofs, pervious areas, roads, etc.).
- Defining the percentage of imperviousness for each surface type.
- Selecting parameters for pervious and impervious areas properties, groundwater properties and pollutant export parameters.

In the study area, there is a total of 21 land lots, 5 of which were empty lots. Through the QGIS measure area tool, the lot size, roof area, driveway area and pervious area were collected from each of the 16 allotments with constructed houses. An average area from those different surface types was taken and applied to the five empty lots, assuming that the construction over these empty lots would soon be undertaken. Figure 1 shows the house allotments from the Green Village site.

Figure 1. Green Village house allotments.

The values from the areas collected for each surface type are depicted in Appendix B. To select the appropriate properties for the surface types, a Water Sensitive SA [4] was consulted, being the critical information to determine those parameters, as follows:

- Soil type: Sandy Clay Loam.
- Land use: Road, Roof or 'All other urban'.
- Lot size: approximately 600 m^2.

The soak-away node on MUSIC was represented by the generic 'Infiltration System' node, as it is a known WSUD infiltration system and there is no available node specifically for soak-aways in the software.

3.7. Re-Dimensioning to the Soak-Away Systems

The parameters of the source nodes that represent one house allotment at Village Green were defined, and the rainfall intensity projections were entered into the MUSIC model. With those two elements, it was possible to run the MUSIC model again and determine the peak flows for each scenario, as shown in Table 2.

Table 2. Scenarios modelled in MUSIC and its respective peak flows.

Year	RCP Projection	Rainfall Intensity Projection: 1.05^{T_m} (from $I_p = I_{ARR} \times 1.05^{T_m}$)	Peak Flow from MUSIC (m^3/s)
Current	N/A	N/A	0.0129
2030	RCP 4.5	1.05	0.0135
	RCP 8.5	1.05	0.0135
2060	RCP 4.5	1.05	0.0135
	RCP 8.5	1.12	0.0144
2090	RCP 4.5	1.12	0.0144
	RCP 8.5	1.16	0.0150

With the preliminary soak-away dimensions obtained by the Argue et al. [35] model (Equation (1)) and the peak flows from Table 2, the re-dimensioning of the soak-away systems was carried out.

Lastly, an optimized design of the soak-away was also modelled using a trial-and-error method from the Argue et al. [35] source control principle, considering the treatment effectiveness of the device. When the size of the soak-away allowed the treatment effectiveness to reach at least 45% of Total Nitrogen (TN) removal, 60% of Total Phosphorus (TP) removal and 80% of Total Suspended Solids (TSS) removal, that size was considered the optimal soak-away area for each scenario analyzed.

4. Results

4.1. Climate Change Projections' Impact on Peak Flows

The influence of climate change in the rainfall dataset is measured through the percentage of increment of the peak flows for the future scenarios (2030, 2060 and 2090), summarized in Figures 2 and 3.

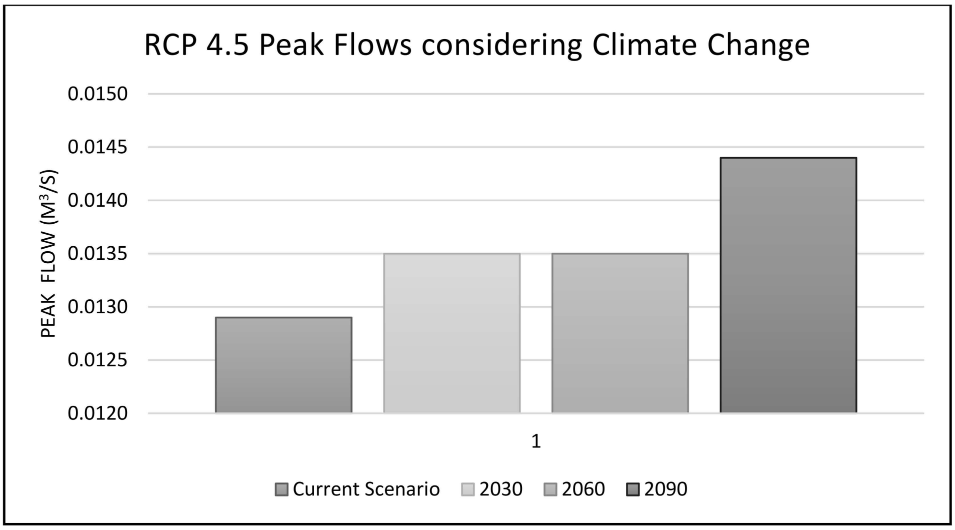

Figure 2. RCP 4.5 peak flows increment considering climate change.

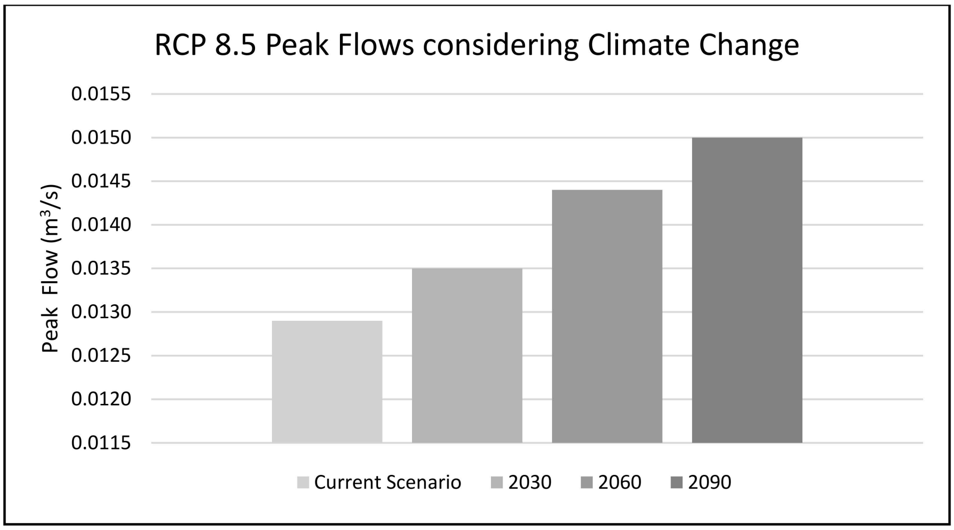

Figure 3. RCP 8.5 peak flows increment considering climate change.

4.2. Re-Dimentioning of Soak-Away Systems

Regarding the area (or 'filter area') of the soak-away, three different methods were applied—the Argue et al. [35] model, MUSIC and trial-and-error optimization. In the first two approaches executed, the increment in the filter area of the soak-away is directly proportional to the percentage of increase of the runoff peak flows due to climate change projections on the rainfall data. This direct relationship occurs because both options apply Argue et al. [35] formulas, where the soak-away area calculation is directly dependent on the runoff volume of allotment and the latter is linearly related to the rainfall intensity/peak flow variables.

On the other hand, for the third approach regarding the 'trial-and-error soak-away optimization', the area of the soak-away is estimated solely based on the treatment effectiveness performance targets. In that case, there is an interesting outcome which shows that for the years 2060 and 2090 RCP 8.5, the soak-away area did not need to be altered to reach the treatment targets, remaining 1.70 m^2, even though the runoff peak flow increased from 2060 to 2090, as can be noticed from Figures 4 and 5.

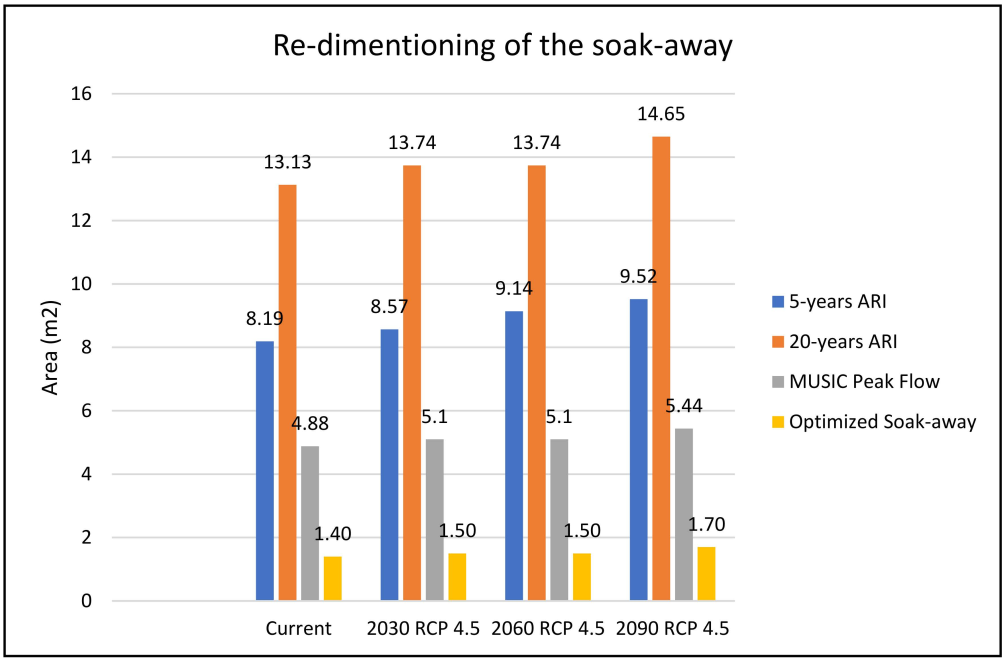

Figure 4. Re-dimensioning of the soak-away for RCP 4.5.

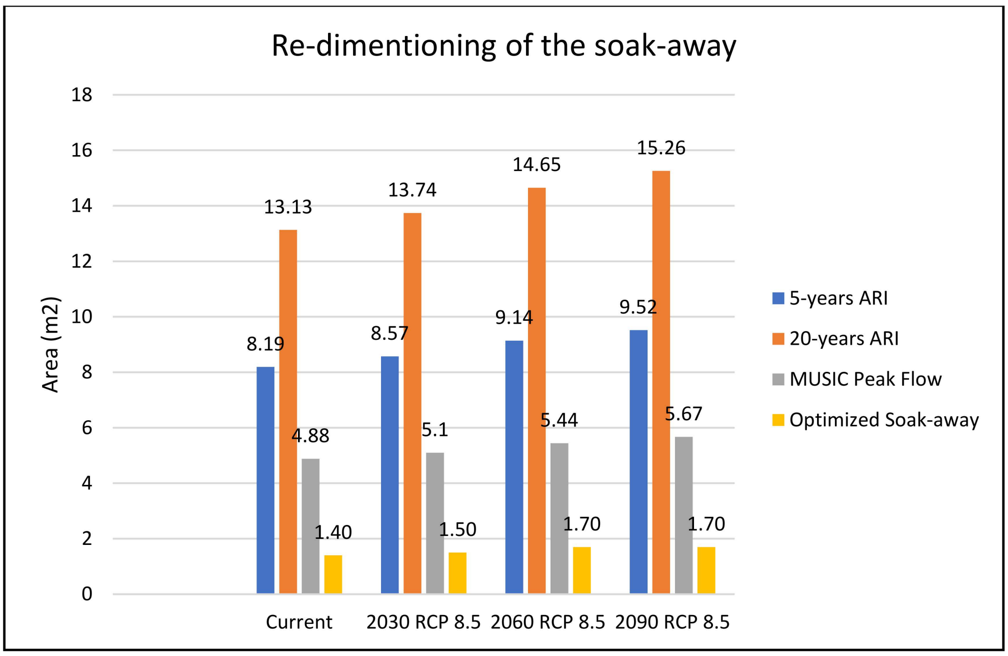

Figure 5. Re-dimensioning of the soak-away for RCP 8.5.

This might have occurred because even though the percentage of increase in the peak flow from the current scenario (2011–2010) to 2090 is 16.28%. When analyzing the percentage of peak flow augmentation from 2060 to 2090, the change in peak flow is much lower, around 4.17%. This slight increment might not represent a major impact on the soak-away performance when receiving that additional amount of runoff flow.

4.3. Treatment Effectiveness of the Soak-Away Systems

The treatment performance of the soak-away systems was evaluated using MUSIC's 'Mean Annual Load' statistical function, which is capable of providing a summary of the overall performance of this particular stormwater treatment node. Considering Water SA [11], the parameters evaluated for the treatment effectiveness of the soak-away systems were:

- Total Suspended Solids (kg/yr)—TSS: 80% reduction target.
- Total Phosphorus (kg/yr)—TP: 60% reduction target.
- Total Nitrogen (kg/yr)—TN: 45% reduction target.

Therefore, when applying the 'Mean Annual Loads' function, the results of the 'percentage of reduction' of those pollutants were taken for all scenarios. It was concluded that all the soak-away designs that were sized using the Argue et al. [35] model achieved more than a 95% reduction of those pollutant concentrations.

For the 'optimized soak-away', where the trial-and-error method was applied to reach the 80% reduction target for the TSS, the sizing of the soak-away filter area needed to be gradually increased, even though the other pollutant concentrations had already reached the desirable reduction target. The TSS percentage of reduction was a limiting parameter to determine the area of the soak-away for this option.

4.4. Costing of Soak-Away Systems

The information about the cost of the soak-away was acquired through MUSIC's 'Life Cycle Costing' function, which includes the costs related to acquiring, installing, maintaining and decommissioning the asset. Table 3 summarizes the estimated costs for those structures in the RCP 8.5 scenarios. The costs related to RCP 4.5 scenarios for 2030, 2060 and 2090 were not shown, as they are equivalent to 2030 RCP 8.5 costs.

Table 3. Life cycle cost of soak-away.

	Life Cycle Cost of Soak-Away (AUD 2022)			
	5-Year ARI Design Flow	**20-Year ARI Design Flow**	**MUSIC Peak Flows**	**Optimized Soak-Away**
Current Scenario	AUD 20,233	AUD 25,994	AUD 15,363	AUD 7905
2030 (1.05 rainfall projection) RCP 8.5	AUD 20,726	AUD 26,627	AUD 15,727	AUD 8201
2060 (1.12 rainfall projection) RCP 8.5	AUD 21,448	AUD 27,547	AUD 16,277	AUD 8765
2090 (1.16 rainfall projection) RCP 8.5	AUD 21,917	AUD 28,149	AUD 16,639	AUD 8765

The results revealed in Table 3 confirm that the Argue et al. [35] model can be considered too conservative when sizing the soak-away system since the cost for the 'optimized soak-away' option is practically half of the cost of the 'MUSIC Peak Flows' option and one-third of the costs associated with the 5 and 20 years ARI methods. On top of that, as mentioned previously, the treatment effectiveness between the '5-year ARI', '20-year ARI' and the 'MUSIC Peak Flows' options range from 95 to 100% for all pollutant concentrations. Therefore, it can be inferred that the methods that adopted the Argue et al. [35] model tended to oversize the soak-away structure and might be considered a 'too cautious' approach.

However, although the costs of the 'optimized soak-away' are more attractive considering the scenarios analyzed, the 'MUSIC Peak Flows' soak-away option may be more suitable considering the unpredictability of the future scenarios. Another important advantage is the fact that the 'MUSIC Peak Flows' option has an area approximately three times bigger than the 'optimized soak-away', costing only double to be implemented, maintained and decommissioned. Furthermore, the treatment effectiveness for that option is close to 100% for all pollutant concentrations analyzed. In view of that, the selection of the 'MUSIC Peak Flows' option might be a reasonable investment to guarantee the desirable performance of the system in the face of climate change uncertainties.

5. Discussions

In the present study, the impact of climate change on rainfall data was analyzed and passed on to infiltration-based soak-away design considerations for a residential allotment at Village Green, Aldinga. The City of Onkaparinga Council provided an approved rainfall dataset that was projected considering the future climate scenarios of 2030, 2060 and 2090 for RCP 4.5 and RCP 8.5. To do so, the ARR guidelines were followed and the CFT tool from CSIRO was applied. Coupled with the rainfall projections, ARR 2016 IFDs were collected and input in stormwater source control principles for soak-away dimensioning. Then, with the information gathered, a MUSIC model was developed for each scenario, and its outcomes were compared and analyzed. The key conclusions made from this research are:

- It was found that, for the lowest representative concentration pathway, RCP 4.5, the years 2030 and 2060 presented the same rainfall projection, and therefore, the soak-away design suffered no alterations, leading to minimum impacts of climate change on WSUD technologies. This makes sense considering that RCP 4.5 is a stabilization scenario that assumes that there will be a medium to high effort to implement climate policies, limiting carbon emissions.
- When assessing the future climate change scenarios, the RCP 8.5 pathway offered a heterogeneity of rainfall projections for the years 2030, 2060 and 2090, showing peak flow increases of 4.65%, 11.63% and 16.28%, respectively, leading to significant impacts of climate change on WSUD technologies.
- In the RCP 8.5 pathway, the need for changing the soak-away design occurred for all future scenarios that were analyzed through the Argue et al. [35] approach, and the changes in area were relatively proportional to the peak flow percentage of increase. However, when only considering the treatment performance targets of the Water Sensitive SA [11], the soak-away areas presented minimum change, and from 2060 to 2090, no alteration to the soak-away size was necessary.
- The treatment effectiveness of the soak-away system was remarkably high for all sizing approaches that used the Argue et al. [35] model, achieving more than 95% reduction of the pollutant concentrations. Nonetheless, when comparing the 'optimized soak-away' option, which was designed only considering the attainment of the treatment targets, those optimized systems were significantly smaller and cheaper than the other design approaches.

6. Conclusions

The impacts of climate change on the soak-away design were mostly evident for the RCP 8.5 emissions pathway, which has been largely considered among the scientific community as the most realistic scenario to account for climate risks. By following the procedures exhibited in ARR guidelines, in conjunction with Argue et al. [35] and the MUSIC model, and comparing the results, it can be stipulated that the Argue et al. [35] approach might potentially add a conservative bias to the results and oversize the layout of the soak-away. Nonetheless, the design of the soak-away system recommended is the one achieved by the combination of MUSIC's Peak Flows and the Argue et al. [35] approach. This design presents a reasonable price and acceptable size for a property owner to implement on their property and guarantees treatment effectiveness. Only the technical performance may not fulfil the goal to adapt climate change impacts on WSUD technologies; it requires the integrated approach of technical, social, economic and political initiatives. Similar studies can also be conducted to understand the environmental impacts of fire caused by climate change on WSUD technologies.

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Appendix A

Figure A1. Green Village house allotments in City of Onkaparinga.

Appendix B

Table A1. Surface types of areas for Green Village house allotments.

p	Roof Area (m^2)	Other Impervious Areas (ex: Driveaway) (m^2)	Pervious Area (m^2)	Lot Area (m^2)
1	298.75	93.88	271.38	664.00
2	315.00	142.00	173.00	630.00
3	390.00	92.00	154.00	636.00

Table A1. *Cont.*

p	Roof Area (m^2)	Other Impervious Areas (ex: Driveaway) (m^2)	Pervious Area (m^2)	Lot Area (m^2)
4	288.00	111.00	230.00	629.00
5	268.00	99.00	263.00	630.00
6	321.00	74.00	241.00	636.00
7	259.00	69.00	212.00	540.00
8	296.00	106.00	131.00	533.00
9	321.00	70.00	146.00	537.00
10	247.00	145.00	136.00	528.00
11	297.00	91.00	221.00	609.00
12	355.00	52.00	283.00	690.00
13	291.00	77.00	235.00	603.00
14	318.00	90.00	130.00	538.00
15	263.00	73.00	210.00	546.00
16	312.00	54.00	229.00	595.00
17	239.00	157.00	272.00	668.00
18	298.75	93.88	289.38	682.00
19	298.75	93.88	313.38	706.00
20	298.75	93.88	293.38	686.00
21	298.75	93.88	487.38	880.00
Total	6273.75	1971.38	4920.88	13,166.00
Average	298.75	93.88	447.35	626.95

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