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Stormwater Harvesting Potential for Local Reuse in an Urban Growth Area: A Case Study of Melton Growth Area in the West of Melbourne

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Abstract: Integrated urban water management approaches (IUWM) are implemented to address challenges from increases in water demand as a result of population growth and the impact of climate change. IUWM aims to utilize all water resources (stormwater, wastewater, and rainwater) based on fit-for-purpose concepts. Here, a local water utility in Melbourne's Melton growth area explored the availability of stormwater as an alternative water resource for water service planning for a proposed residential development in an existing greenfield area of 13,890 hectares for 160,000 new houses by 2040. A methodology was developed for assessing the stormwater quantity and quality under land use change and different climatic conditions considering the availability of stormwater from the proposed urban development. The modelling results indicated that the amount of annual stormwater generated in the region increased by nearly four times to 32 GL/year under the 2040 full urban land use with high climate change. The provision of constructed wetlands in proposed development blocks was found to be efficient at removing TSS, TP, and TN, and able to retain over 90% of TSS, 77% of TP, and 52% of TN in all scenarios. Harvested stormwater, if treated to potable standards, can meet nearly 40% of water requirements for residential area needs.

Keywords: stormwater harvesting; water quantity; water quantity; urban water demand; integrated urban water management; runoff modelling

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1. Introduction

Urbanisation, population growth, and climate change have a significant impact on fresh water resources, in particular for rapidly growing urban developments around the world [1,2]. The increasing conversion of natural landscapes into impervious areas is a common phenomenon in most parts of the world. With urbanisation, pervious surfaces dominated by vegetated surfaces such as agricultural lands, greenfields, and forests are replaced with impervious areas such as roads, rooftops, and paved areas including parking lots. Urbanisation involves expansion associated with high population growth and rural exodus. The current world population is 8 billion and is projected to increase by 21% in 2050 [3]. The state of Victoria, Australia, also follows an upward trend, as the population increased from 1.9 million in 1960 to 6.7 million people today. This figure is expected to reach between 10.1 million and 14.5 million by 2066, according to the Australian Bureau of Statistics [4]. It is predicted that the gap between water supply and demand is most likely to increase in the future due to population growth, thereby putting an additional load on water supply systems.

Existing pressure on water resources can also be exacerbated by climate variability. Global greenhouse gas concentrations have been trending upwards since the mid-19th century. Local temperature trends in Victoria, Australia, over a similar period are of a similar magnitude to global trends [5]. Increased greenhouse gas concentrations and associated changes to the global climate system have resulted in changes in the behaviour of Victoria's climate, with obvious reductions in rainfall in the cool season, i.e., April to October, in past decades [6]. CSIRO used global climate models (GCMs) to predict anticipated changes in climate of Victoria's river basins for the year 2040. The results of the GCMs indicated that Victoria will become hotter and drier under increased greenhouse gas concentrations. Under the high climate change scenario, for example, the average daily temperature is predicted to rise by 1.6 °C by 2040. The overall reduction and increase in annual average rainfall and potential evapotranspiration are projected to be 12.1% and 5.6% by 2040, respectively [7]. There is thus a fundamental concern that ongoing global greenhouse warming will put pressure on water resources due to reductions in water availability [6]. Hotter and drier conditions increase the water demand for intended end-use applications, i.e., non-potable uses [8] and potable uses [9].

The projected population growth due to urbanisation, increased water demand, and concerns about future climate variability have highlighted the need to manage water resources in a more sustainable way [10]. Stormwater harvesting, i.e., capturing runoff from urban areas to provide a source of non-potable, and in some cases potable water supply, is now acknowledged as a valuable resource to urban development areas, where a set of resilient urban water supply sources is needed [11,12]. Stormwater runoff is drained directly to streams via man-made drainage systems and is also a major source of a wide range of pollutants, and is thus identified as a primary degrader that stresses receiving waterbodies [13–15]. Hence, mitigating stormwater pollution is essentially required in urban water management to transform cities and towns into the most resilient and liveable in the world. Water sensitive urban design (WSUD) approaches are now implemented to minimise stormwater runoff and pollutant loads into the receiving environment [16].

Inamdar et al. [17,18] developed a GIS-based screening tool for locating and ranking suitable stormwater harvesting sites in urban areas and for the evaluation of selected stormwater harvesting sites using multi criteria decision methodology. Such approaches can be used to prioritise decentralised stormwater harvesting projects based on demand and supply considerations. Sapkota et al. [19] further developed a methodology for integrated evaluation of hybrid water supply systems. Sharma et al. [20] conducted a study to use alternative water resources based on a fit-for-purpose concept for a 3060-hectare urban development planned for a population of 86,000. Based on the study, it was assessed that nearly 28% of freshwater could be saved by using locally harvested stormwater for toilet flushing and garden watering. The savings could be increased further if the end usages can be extended, thus improving the treatment processes. Overall cost and raw stormwater storage size are known challenges to such systems due to seasonal variability in stormwater flows.

Sanciolo et al. [21] conducted a literature review for potential uses of harvested stormwater, with a focus on potable reuse applications, stormwater quality, and the requirements to treat stormwater to potable standards. The microbial and chemical quality of stormwater treated using two typical potable reuse treatment trains was modelled and compared with stormwater log-reduction targets from the literature and to drinking water guidelines. The cost of these treatments for current and expected future stormwater volumes was also estimated based on the literature costings.

Urban stormwater runoff quality statistics are essential for planning any treatment process for potable and non-potable applications based on a fit-for-purpose concept. Nature-based and engineered treatment processes alone or in combination can be planned for the desired degree of water quality treatment. Various researchers have investigated urban stormwater pollutants, their sources, and pollutant processes [22–24]; however, catchment-specific stormwater quality statistical information (e.g., 95th percentile data) would be required for the planning and design of the treatment processes. This is a major challenge, as stormwater's spatio–temporal variability necessitates monitoring a large number of pollutants over an extensive period to ensure the capture of a full range of events, such as a heavy rainfall event or sewer overflow, which could lead to an increase in the individual pollutant level. This challenge is exacerbated by the need to also take into account contaminants of emerging concern. These are contaminants that are not commonly monitored, making the task of meaningful statistical analysis of their level in stormwater difficult without further extension of the monitoring period and detailed investigation.

A methodology is presented here for assessing the stormwater quantity and quality under land use change and different climatic conditions for the availability of alternative water resource for water services planning for new developments. It is hoped that this publication will help water professionals in assessing alternative water resources for similar regional developments across the globe for water resources services planning.

2. Case Study Area

The growth area boundary was provided by the local water utility "Greater Western Water", and encompasses the entire area of urban precincts included in the Melton-Rockbank Precinct Structure Plan (PSP) (Figure 1). The entire area in PSP was included in the modelling to provide an indication of the maximum stormwater harvesting potential from this area. The urban growth area was split into six urban blocks (blocks 1–5, with block 1 further split into blocks 1A and 1B (Figure 1)). The specified urban growth blocks nominated by the water utility were included in the model at the 2040 development level, assumed as 100% urban land use. Blocks 1A and 4 were located within the natural Werribee River catchment and thus stormwater from these areas was gravity-fed into the Werribee River. Nearly 62% of the total catchment of block 1B also drained naturally to the Werribee River via Toolern Creek, whereas the remaining 38% drained to the Kororoit Creek, which is outside of the Werribee River catchment. Blocks 2, 3, and 5 were not within the natural stormwater catchment of the Werribee River and thus scenarios that included stormwater from these blocks assumed that additional stormwater runoff harvested from these blocks would be pumped into the nearby Merrimu Reservoir (not shown) based on onsite treatment level. The vision for this stormwater harvesting scheme investigation was to explore availability of alternative water resources for water planning of the proposed development. An assessment is required for stormwater quality and quantity from the proposed area once it is fully developed. The urban blocks were considered based on the Melton-Rockbank Precinct Structure Plan (PSP) [25].

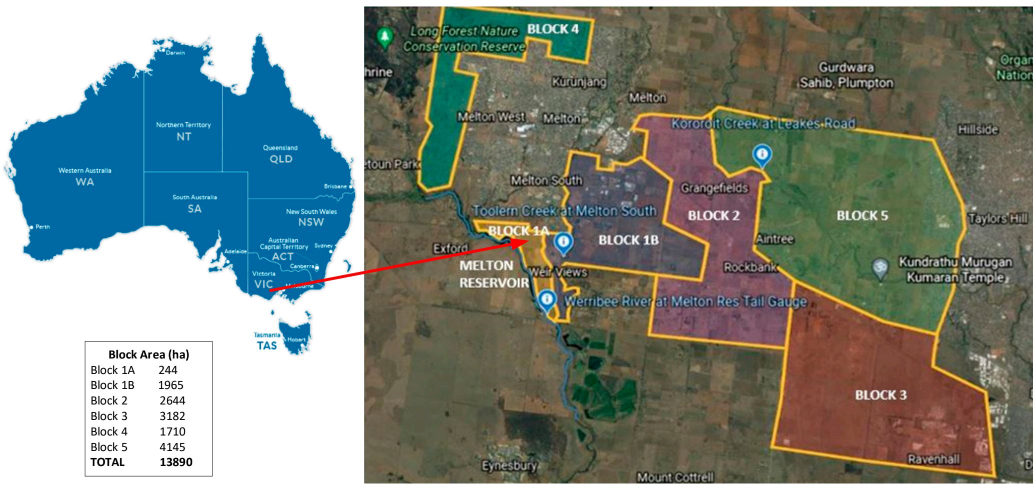

Figure 1. Melton-Rockbank Precinct Structure Plan (PSP) (West of Melbourne region) overlaid with urban block boundaries modelled as part of the current investigation (modified from [25]).

3. Proposed Methodology for Assessing Stormwater Harvesting Potential and Associated Water Quality

A literature review was conducted to investigate the current methodologies for the stormwater harvesting from an upcoming urban development. Various water systems and service-associated assessment methodologies are available in the literature [20,26–28]. These approaches mainly cover the integration of various analyses and design methods specific to urban water services. A conceptual diagram of the stormwater harvesting and potential reuse is depicted in Figure 2 below.

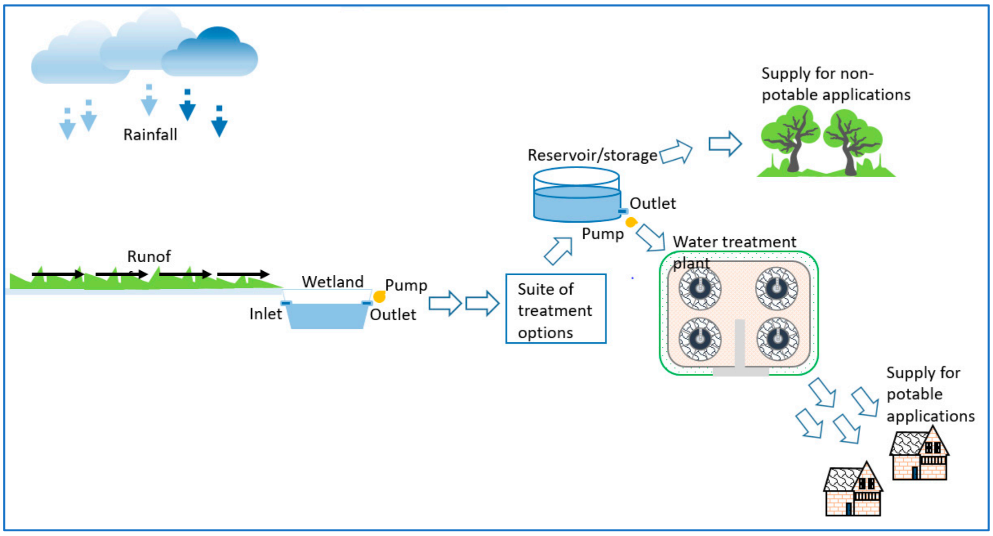

Figure 2. Conceptual diagram showing stormwater runoff generation and treatment.

Considering the varying nature of urban developments in greenfield areas and learning from existing literature, a generalised methodology for the assessment of the stormwater harvesting potential and associated water quality for treatment needs was developed, as depicted in Figure 3. The methodology is described in the following steps:

(1) ***Understand Specific Development Area Conditions and Environment:*** This step involves the collection of development-specific information for planning and executing the study. This will include, but not be limited to, existing development, if any, in the proposed area and the nature of existing land use, development plan and its area, number of blocks or sub-divisions and their areas, current and future climate data, local soil properties, household occupancy rates, industrial and commercial developments in the area, stormwater treatment/disposal options and constraints, and regulatory policies and guidelines. Engagement with project-specific stakeholders, e.g., local water utility, local government, and environmental agencies, should be made for information on the development of specific policies and guidelines, including establishing study objectives.

(2) ***Establish Development-Specific Study Objectives in consultation with local stakeholders:*** Study-specific objectives should be developed in consultation with stakeholders. These are generally based on site specific constraints such as the availability of limited fresh water resources, disposal of stormwater, and wastewater limitations in the area. These objectives can be quantitative or qualitative in nature. For example, the reduction in annual stormwater flow by 40% from the development is a quantitative objective, while minimizing stormwater flow from the development is qualitative. Some examples of objectives for the new development area can be maximizing application of local alternative water resources, minimizing the pressure on the freshwater resources, low or minimum impact on existing natural environment, minimizing waste/contaminants to natural environment, and low cost to community and wider social acceptance of the development specific objectives for the proposed study. Local project objective-specific guidelines should be considered for developing qualitative and quantitative objectives.

(3) ***Develop Planning Horizon and Study Analysis Period:*** This will include understanding the planning horizon of the proposed development, timeline of development

phases, and associated development sizes including nature of development (residential, commercial, industrial, and recreational). The study analysis period will be decided based on the overall development plan and timeline of development phases over the planning horizon.

(4) ***Estimate Water Demand for the Proposed Development:*** The proposed nature of development (residential, commercial, industrial, and recreational) should be used to estimate the annual water demand over the planning horizon and development timelines based on local water consumption guidelines for various intended usages. The breakdown between potable and non-potable demand should also be conducted to estimate the potential for alternative water source applications.

(5) ***Select Suitable Modeling Tool for Analysis:*** The selection of the most appropriate modeling tool is generally dependent on model capabilities for intended applications to meet study objectives, professionals' preferred models at geographic locations and data requirements, ease of availability, and associated cost.

(6) ***Establish Scenarios for Stormwater Runoff Quantity and Quantity Assessment:*** The scenarios for modeling stormwater runoff and associated water quality are developed considering existing land use, provision of water-sensitive urban design approaches, future urban land use, climate change impacts (low, medium, and high), and natural/manmade flow of stormwater from various blocks (sub-catchments) to the receiving environment.

(7) ***Model Set-up:*** The selected modeling tool is applied for developing a model for the development area based on the development plan, soil characteristics, drainage flow paths, stormwater-receiving environment, and proposed WSUD approaches.

(8) ***Assess Scenarios Applying Modeling Tool:*** The selected scenarios are modelled using the selected tool for the estimation of stormwater runoff as the maximum harvesting potential under various climatic conditions and scenarios. The stormwater quality is also modelled under various scenarios.

(9) ***Establish Stormwater Quantity and Quality from the Proposed Development:*** Check stormwater harvesting potential under various scenarios as water resources for the proposed urban development for water services planning and associated water quality to develop appropriate treatment trains.

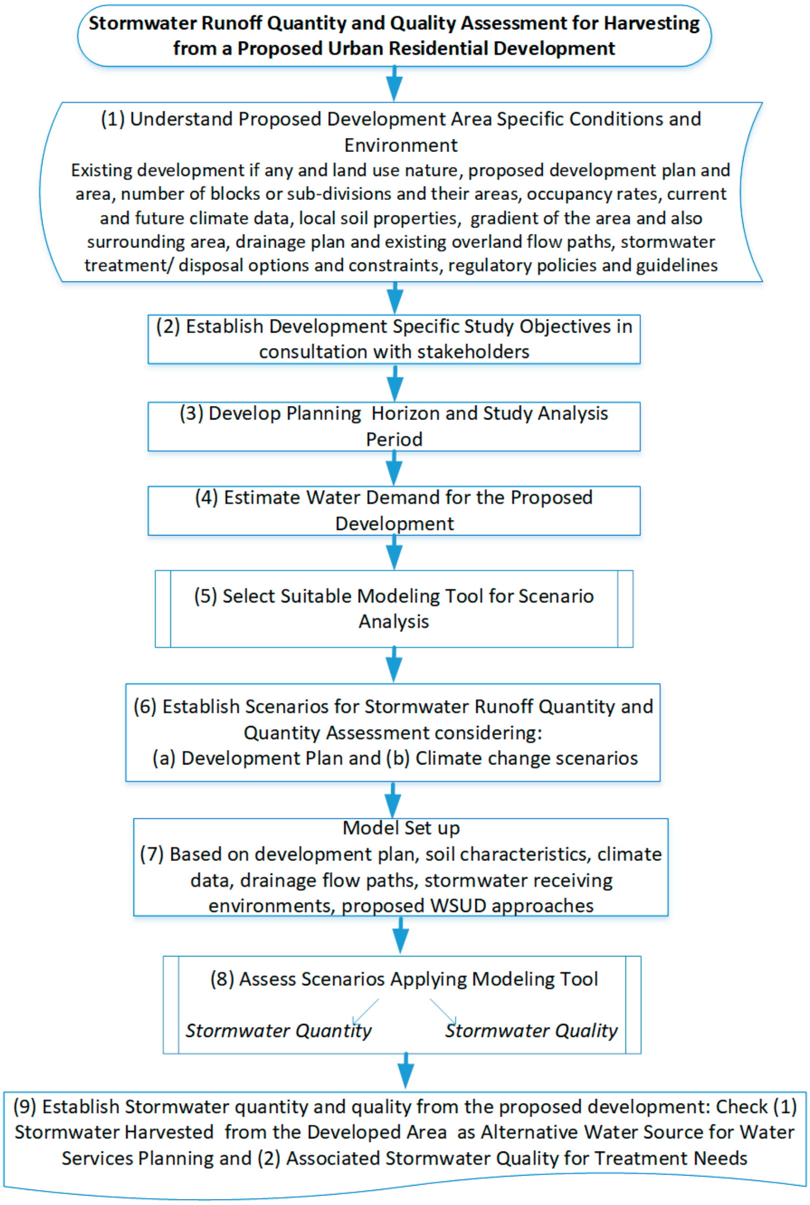

Figure 3. Proposed methodology flow diagram for stormwater quality and quantity assessment.

4. Application of Assessment Methodology

The application of the developed methodology for the assessment of stormwater quantity and quality is conducted in this section and the results are presented.

4.1. Understanding of Development Area Specific Conditions and Environment

The data and information collected about the planned urban development in a greenfield area are documented in this section for modelling purposes.

4.1.1. Existing Land Use and Proposed Urban Development

The proposed urban development area is shown in Figure 1. The total area of the proposed development is 13,890 hectares. The block-specific areas of the proposed development are provided below in Table 1.

Table 1. Melton-Rockbank Precinct planned urban block areas.

Blocks	Area (Hectare)
Block 1A	244
Block 1B	1965
Block 2	2644
Block 3	3182
Block 4	1710
Block 5	4145
Total	13,890

The development area and stormwater flow paths from various blocks have been described in detail in Section 2 (case study area). The existing use of land was primarily for dry land grazing and cropping.

4.1.2. Climate Data

The recent 22-year record of daily rainfall and potential evapotranspiration (PET) data (2000–2021) from the Little River Station (station no: 087033) taken from Scientific Information for Land Owners (SILO) (https://www.longpaddock.qld.gov.au/silo/about/ assessed on 25 March 2023) is shown in Figure 4. The average daily rainfall depth and PET were 1.25 mm and 3.91 mm, respectively.

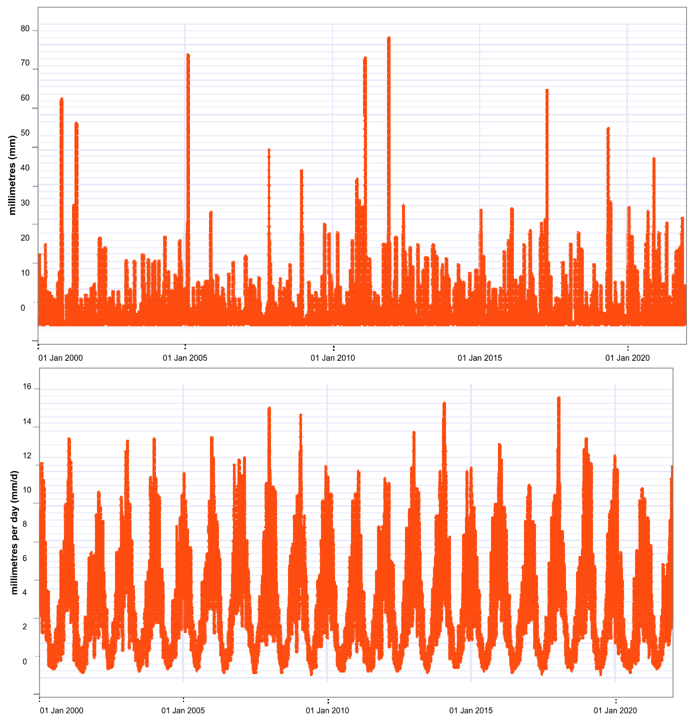

Figure 4. Time series of the 2000–2021 rainfall (**Top**) and PET (**Bottom**).

Various climate change impact scenarios for rainfall and PET were considered for the modelling, as listed below, in accordance with the DELWP guidelines [6]:

- Low-impact climate change: current rainfall and PET factored up by 2.2% and 2.9%, respectively
- Medium-impact climate change: current rainfall factored down by 2.7% and PET factored up by 4.7%.
- High-impact climate change: current rainfall factored down by 11.7% and PET factored up by 5.9%.

DELWP [6] provides guidance for long-term temperature, potential evapotranspiration, rainfall, runoff, and recharge to be used across Victoria to assess the impact of climate change on water supplies. Three representative climate change projections (low, medium, and high impact) were selected from the range of possible climate futures anticipated by 42 different global climate models (GCMs).

4.1.3. Soil Type: Soil Parameters for Modeling

The area is on the Keilor–Werribee plain, which is part of a lava plain. The texture of the soil is mostly basalt-derived cracking clay that has a poor drainage rate. The soil becomes water logged in wet weather and dries in the warm weather [29]. A soil storage capacity of 120 mm and field capacity of 50 mm was adopted for stormwater runoff estimation, as per the Melbourne Water Guideline [30].

4.2. Establishment of Development Specific Study Objectives in Consultation with Stakeholders

The aim of this study was to investigate stormwater harvesting potential from the proposed development for planning the reuse of this resource under integrated urban water management approaches to reduce the load on fresh water resources. The impact of climate change on the stormwater harvesting potential was also an important factor to investigate. It is also required to investigate stormwater quality from harvested stormwater through modelling for the development of appropriate treatment trains for intended use in future research.

Thus, the objectives of this research are as follows:

(a) Investigate the stormwater harvesting potential under current and future land use changes as well as low, medium, and high climate change impacts without and with the planed provisions of wetlands in each of the development blocks.
(b) Investigate the stormwater quality parameters under various conditions as mentioned in (a) for future investigation on the treatment train to treat water for fit-for-purpose applications.

These study objectives were developed in consultation with the main stakeholder (local water utility) and regular fortnightly meetings were organised for ongoing input during the execution of the project with the water utility.

4.3. Development of Plan Timeline and Analysis Period

It is expected that the planned urban area will be fully developed by 2040. Thus, for modelling purposes, the base case (current land use) analysis was planned for 2022 and for 2040 for the fully urban developed condition.

4.4. Estimation of Water Demand for Proposed Development

Melbourne Water Utilities are now running a program on water conservation called "Target 150", which is a voluntary water conservation initiative by the Victorian Government. It aims to encourage people to be mindful of our precious resource of water and to reduce our average daily water use to below 150 litres per person (https://www.water.vic.gov.au/liveable/using-water-wisely/t150 assessed on 26 March 2023). The Department of Sustainability and Environment, Victoria, Australia [31], also published a document for achieving target 155. This target did not apply to recycled, reclaimed, rain, or grey water, except where supplemented by drinking water [32]. The average occupancy rate in Melbourne was 2.6 person for a 2019–2020 reference period (https://www.abs.gov.au/ assessed on 26 March 2023). As the development plan was in the initial stages, only the approximate residential water demand for fully urban development could be estimated. Considering the proposed 160,000 homes in the area, occupancy rate of 2.6 person per home (total residential population 416,000) and per person daily water requirement of 150 litres, the water demand per year could be estimated as 23 GL/year at the fully developed stage. The water demands for commercial, industrial, and recreational purposes in the development area were difficult to estimate at this stage and thus were not included.

4.5. Selection of a Suitable Tool for Hydrological and Water Quality Modeling

The search for a suitable modelling tool was conducted, considering the aims of the study. The stormwater harvesting potential, once the proposed development was fully developed, and the associated water quality parameters were investigated under various climate impact scenarios. Devi et al. [33] conducted the review of various hydrological models and briefly discussed the variable infiltration capacity model (VIC), TOPMODEL, HBV, MIKESHE, and soil and water assessment tool (SWAT) model. This review was mainly focused on agriculture land use and indicated that each model has its own unique characteristics and respective applications. There was not a single valid model fitting every purpose [34]. Beven and Young [35] highlighted that the model should not be more complex than necessary and should be fit-for-purpose. Elga et al. [36] conducted a review of 43 selected modelling approaches, including MUSIC v1.10 software dealing with urbanization at the catchment scale or city scale. MUSIC continuously simulates catchment runoff for a given rainfall and evapotranspiration time series at a user-defined time step from 6 min to 24 h [37]. Imteaz et al. [38] conducted a study on the accuracy of MUSIC estimations for different stormwater treatment options used in Australia and abroad. Data on several field measurements on different constructed stormwater treatment systems (bioretention, grass swale, and porous pavement) in Australia, Sweden, New Zealand, and Scotland were collected from the literatures. In general, they found that MUSIC could simulate flow conditions with good accuracy; however, MUSIC's predictions on the removal efficiencies of total suspended solids (TSS), total phosphorus (TP), and total nitrogen (TN) were varying. Since then, eWater Australia recently released a new version of MUSIC software (as MUSICX) (https://ewater.org.au/musicx-v1-10/ assessed on 15 November 2021) with enhanced capabilities around data analysis and results interpretation. Moreover, Melbourne Water [30] developed guidelines for MUSIC modelling approaches and input parameters for the local area, including case study development. Shahzad et al. [39] recently verified the ability of MUSIC to represent the catchment runoff peak flow and volume in a satisfactory manner with appropriate parameters in an urban case study development.

eWater MUSICX software (https://ewater.org.au/musicx-v1-10/ assessed on 15 November 2021) was finally selected for this study considering its wider application for stormwater quality and quantity modelling, and the availability of local guidelines for the model's application and input parameters developed by Melbourne Water [30].

4.6. Establishment of Scenarios for Stormwater Runoff Quality and Quantity Assessment Considering Development Plan and Future Climate Change Impacts

The scenarios comprised an analysis of the current and future (2040) land use conditions in the growth area, as well as climate change scenarios according to the global climate models proposed by the Department of Environment, Land, Water, and Planning, Victoria, Australia [6]. Modelled stormwater quality was also included in the investigations to assess the potential risks associated with the diversion of stormwater from wetlands to the reservoir under various scenarios. The scenarios for stormwater quality and quantity modelling are listed in Table 2. These scenarios are based on the following current and future development conditions:

- Current agricultural land use and climate with and without the impacts of wetlands where stormwater from specific agricultural blocks flowed naturally into the Melton Reservoir with no stormwater being harvested and diverted to storage from some of the other blocks.
- Future (2040) fully urbanised land use with the impact of climate change scenarios in the absence and presence of wetlands, where additional stormwater from specific urban blocks was also captured and piped into the Melton Reservoir.
- The current climate data are based on a 2000–2021 time series and its modification to reflect climate change impacts are described in Section 4.1.2.

Table 2. Summary of scenario description and MUSICX model inputs.

Scenario	Scenario Description	Analysis Year	Land Use	Climate Change Impact	Wetlands	Stormwater Flow
S 1	Current land use and climatic conditions and no wetland in blocks	2022	100% agricultural use–10% Imperviousness	No climate impact Use 2000–2021 climate data	None proposed	Blocks 1A and 4 flows naturally into the Melton Reservoir (MR)
S 2	Current land use and climatic conditions and wetland in blocks	2022	100% agricultural use–10% Imperviousness	No climate impact Use 2000–2021 climate data	Proposed in blocks 2% of block area	Blocks 1A and 4 flows naturally into the MR
S 3	Future 100% urban land use and low impact climate and no wetland in blocks	2040	100% urban land use–75% Imperviousness	Low climate impact	None proposed	Blocks 1A and 4 flows naturally into the MR while stormwater from block 1B, 2, 3, and 5 is captured and pumped to MR
S 4	Future 100% urban land use and low climate impact and wetland in blocks	2040	100% urban land use–75% Imperviousness	Low climate impact	Proposed in blocks 2% of block area	Same as for Scenario 3
S 5	Future 100% urban land use and medium climate impact and no wetland in blocks	2040	100% urban land use–75% Imperviousness	Medium climate impact	None proposed	Same as for Scenario 3
S 6	Future 100% urban land use and medium climate impact and wetland in blocks	2040	100% urban land use–75% Imperviousness	Medium climate impact	Proposed in blocks 2% of block area	Same as for Scenario 3
S 7	Future 100% urban land use and high climate impact and no wetland in blocks	2040	100% urban land use–75% Imperviousness	High climate impact	None proposed	Same as for Scenario 3
S 8	Future100% urban land use and high climate impact and wetland in blocks	2040	100% urban land use–75% Imperviousness	Medium climate impact	Proposed in blocks 2% of block area	Same as for Scenario 3

4.7. MUSIC Model Set-Up

4.7.1. Development Area Representation in MUSICX Model

MUSICX was used to simulate stormwater runoff volume, total suspended solids (TSS), and nutrient loads, e.g., total nitrogen (TN) and total phosphorus (TP), from the defined urban growth area, under current (assumes 100% agricultural land use) and future fully urbanized land use conditions and climatic variability. Details of the general scenario setup are provided in Table 2. Two examples of the model configuration in MUSICX are also shown in Figure 5.

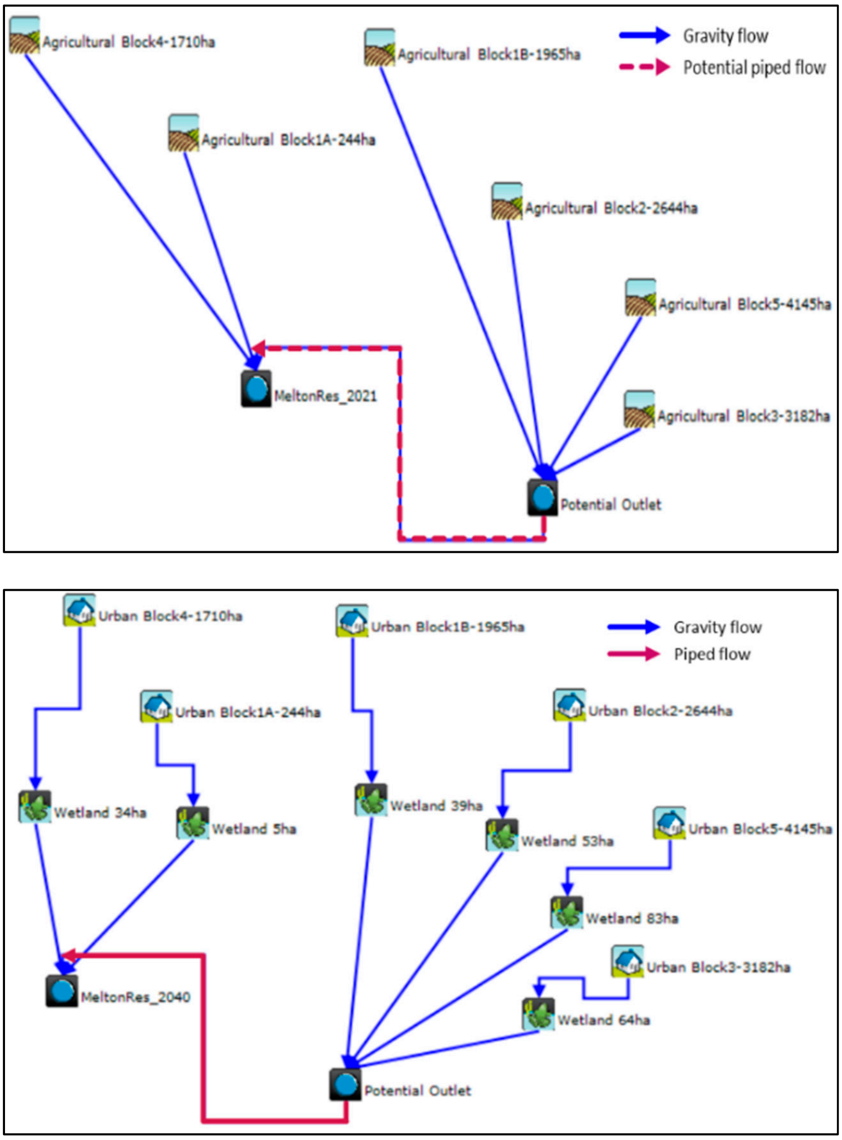

Figure 5. MUSICX model configuration of the Melton growth area under existing agricultural land use in the absence of the wetlands (**top**) and future urban development in the presence of the wetlands in 2040 (**bottom**).

Stormwater from blocks 1A and 4 flows was assumed to flow naturally into the Melton Reservoir. The additional stormwater generated in 2040 from Blocks 1B, 2, 3, and 5 is assumed to be piped and pumped to the Melton Reservoir or another suitable reservoir for subsequent treatment and reuse. Each wetland is assumed to have an area of 2% of the corresponding sub-catchment area based on a previous study [25].

The MUSICX model was developed for stormwater quality and quantity modelling in this study, with some key updates and amendments based on recent Melbourne Water

MUSIC guidelines [30]. These corresponded to key parameters around rainfall-runoff and impervious land fractions, as shown in Table 3. For all sub-catchment areas defined as urban land use, an average impervious land fraction of 0.75 was adopted in the model based on standard residential densities (lot size). Table 1 above shows the sub-catchment area of urban blocks for MUSICX modelling. As there were no local streamflow data available for proposed development to conduct calibration of a hydrlogical model, stormwater modelling parameters were selected from MUSIC software guidelines developed for the Melbourne area [30].

Table 3. Rainfall-runoff parameters and impervious fractions [30].

Rainfall-Runoff Parameters	**MW Guidelines, 2022 [30]**
Soil storage capacity (mm)	120
Field capacity (mm)	50
Zone description	Normal range
Large Residential (Lot size 601–1000 m^2)	0.5–0.8
Standard densities (Lot size 300–600 m^2)	0.7–0.8
High densities (Lot size < 300 m^2)	0.8–0.95

A range for future climate conditions, for the 'low', 'medium', and 'high' impact climate scenario, were selected from climate change guidelines [6] to estimate expected future conditions. All of these scenarios were investigated in the absence and presence of wetlands.

4.7.2. Wetland Parameters for Modelling

The MUSICX model used wetlands as a treatment option to meet the stormwater quality objectives, as defined in the Urban Stormwater Best Practice Environment Management Guidelines (BPEMG) [40]. The objectives include the following:

- 80% retention of the typical urban annual load for total suspended solids (TSS).
- 45% retention of the typical urban annual load for total phosphorus (TP).
- 45% retention of the typical urban annual load for total nitrogen (TN).

The area of the wetlands was estimated to be 2% of the total sub-catchment area for each block to meet the BPEMG target of urban nutrient load reduction [25]. The notional detention time was greater than 72 h. MUSICX outputs were generated, demonstrating that wetland treatments achieved BPEMG for stormwater treatment. The wetland parameters configured in the MUSICX model are shown in Table 4.

Table 4. Wetland parameters configured in the MUSICX model [25].

Wetland Design Parameter	**Block 1A**	**Block 1B**	**Block 2**	**Block 3**	**Block 4**	**Block 5**
Low flow bypass (m^3/s)	0	0	0	0	0	0
High flow bypass (m^3/s)	100	100	100	100	100	100
Inlet pond volume (m^3)	5000	39,000	53,000	64,000	34,000	83,000
Surface area (m^2)	50,000	390,000	530,000	640,000	340,000	830,000
Extended detention depth (m)	0.35	0.35	0.35	0.35	0.35	0.35
Permanent pool volume (m^3)	20,000	156,000	212,000	256,000	136,000	332,000
Initial volume (m^3)	20,000	156,000	212,000	256,000	136,000	332,000
Exfiltration rate (mm/h)	0	0	0	0	0	0
Evaporative Loss as % of PET	125	125	125	125	125	125
Equivalent Pipe Diameter (mm)	220	600	700	775	575	875
Overflow Weir width (m)	3	3	3	3	3	3
Notional Detention Time (h)	73	76	76	75	73	77

4.7.3. Stormwater Quality Parameters for Modeling

No amendments were made to the constituent MUSICX model parameters for TSS, TP, and TN as no field testing had been implemented to estimate the build-up and wash-off parameters. Default values for pollutant loadings were used in MUSICX, as shown in Table 5.

Table 5. Default pollutant loading concentrations for different land use and constituents.

Land Use	Event	Concentration (mg/L)					
		TSS		TP		TN	
		Mean	St. Dev	Mean	St. Dev	Mean	St. Dev
Agricultural	Base flow	25.12	1.35	0.13	1.35	1.18	1.35
	Storm flow	199.53	2.04	0.54	2.00	3.89	1.82
Urban–mixed	Base flow	12.59	1.48	0.15	1.55	2.09	1.32
	Storm flow	158.49	2.09	0.35	1.78	2.63	1.55

Various model parameters were selected based on the local guidelines for MUSIC modelling [29], as listed in Tables 3–5. As there were no stream flow data available at this stage to calibrate and validate the model, local guidelines were considered suitable for the model parameters at this stage.

4.8. Assessment of Options–Stormwater Runoff Quantity and Associated Quality

4.8.1. Stormwater Runoff Quantity from Various Scenarios

The annual average stormwater runoff volume for six blocks was estimated for different existing and future scenarios in the absence and presence of the wetlands, as shown in Table 6. Some of the key results are stated below:

- The volume of stormwater was proportional to the size of the blocks, with a larger area resulting in a greater stormwater volume. The runoff volume was lowest for the smallest block 1A and highest for the largest block 5 (see Tables 1 and 6).
- All future urban development scenarios resulted in a higher stormwater runoff volume due to increases in the impervious surface compared with the existing agricultural land use. For instance, stormwater runoff increased by nearly four times to be 32 GL/year under the 2040 full urban land use with high climate change (most conservative scenario) compared with 8.39 GL/year of stormwater generated today, assuming there were no wetlands built out there.
- The volume of stormwater available in the region decreased after the construction of wetlands, mainly due to ET losses in the wetlands under various scenarios.

Once rainfall and PET were rescaled in line with the DELWP guidelines for climate change for future scenario analysis [6], the runoff from the region changed to the following:

- Assuming no wetlands are constructed in the region, annual average stormwater volume increased to be 38.62 GL under the 2040 full urban land use with the low-impact climate. This decreased by 6% and 17% to 36.25 and 32 GL with the medium and high-impact climates, respectively.
- With the construction of wetlands in each block, annual average stormwater volume increased to 33.53 GL under the 2040 full urban land use with low-impact climate. This decreased by 7% and 20% to 31.08 GL and 26.78 GL with the medium and high-impact climates, respectively.
- The 8.39 GL/year of stormwater available today (if completely harvested) contributed to meeting the required amount of potable and Class B recycled water (7.5 GL/year,

reported by Greater Western Water), which is mainly used for irrigation of open spaces in the Melton growth area. Here, 26.78 GL/year stormwater generated under the 2040 full urban land use with a high-climate impact and the provision of wetlands was sufficient to meet residential potable water demand of 23 GL/year if 100% stormwater is captured and treated for potable standard.

Table 6. Water balance for each block under various land use (existing agricultural and future urban development) and climate conditions (low, medium, and high-impact climates).

Description		Water Balance (ML/Year)						
		Block 1A	Block 1B	Block 2	Block 3	Block 4	Block 5	Total
Existing Agricultural and climate scenarios 1 and 2	(S 1) Total outflow without wetlands	147.46	1187.56	1597.91	1923.06	1033.45	2505.05	8394
	ET Loss from wetlands	73.43	579.45	784.72	946.41	504.78	1229.36	4118
	(S 2) Total outflow with wetlands	74.03	608.11	813.19	976.65	528.67	1275.69	4276
Future Urban Development, Low Climate Impact Scenarios 3 and 4	(S 3) Total outflow without wetlands	678.45	5463.75	7351.74	8847.67	4754.72	11,525.32	38,622
	ET Loss from wetlands	91.41	713.61	969.80	1171.17	622.00	1518.95	5087
	(S 4) Total outflow with wetlands	578.04	4750.14	6381.94	7676.50	4132.72	10,006.37	33,526
Future Urban Development, Medium Climate Impact Scenarios 5 and 6	(S 5) Total outflow without wetlands	636.87	5128.88	6901.15	8305.39	4463.30	10,818.93	36,255
	ET Loss from wetlands	92.91	725.52	985.98	1190.66	632.35	1544.33	5172
	(S 6) Total outflow with wetlands	543.96	4403.36	5915.17	7114.73	3830.95	9274.60	31,083
Future Urban Development, High Climate Impact Scenarios 7 and 8	(S 7) Total outflow without wetlands	562.18	4527.36	6091.77	7331.33	3939.84	9550.08	32,002
	ET Loss from wetlands	93.72	731.95	994.69	1201.09	637.94	1558.02	5217
	(S 8) Total outflow with wetlands	468.46	3795.41	5097.08	6130.24	3301.90	7992.06	26,785

The stormwater runoff from each block under is summarised in Table 6 and depicted in Figure 6. There could be around 50% ET losses for the total runoff with the provision of wetlands in scenario 2 considering the current development condition. However, this was reduced to 15% of the total runoff when the area was fully developed (Table 6). Overall, the ET losses were of the order of 4–5.2 GL/year due to wetlands for all the scenarios.

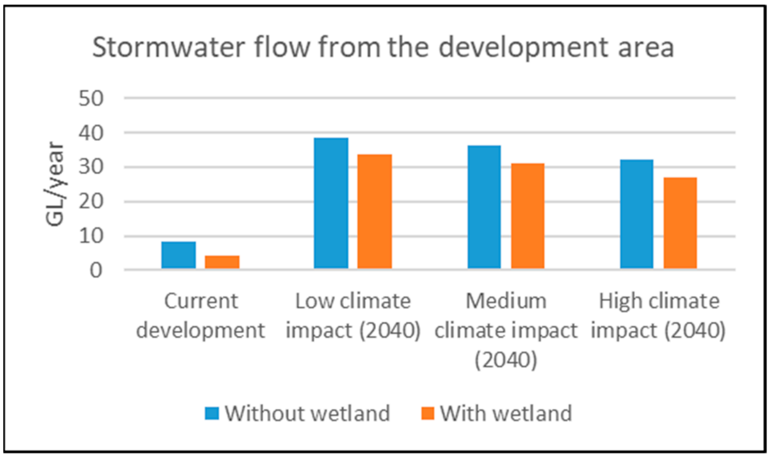

Figure 6. Stormwater runoff quantity from the development under various land-use development and climate change conditions.

4.8.2. Stormwater Pollutant Load from Various Scenarios

The MUSICX model also estimated the loads of TSS, TP, and TN from six blocks for different scenarios in the absence and presence of wetlands from stormwater runoff. Some of the key results are stated below:

- As expected, the loads of pollutants generated were proportional to the size of the blocks, with a larger area resulting in greater pollutant loadings. The pollutant loading was lowest for the smallest block 1A and highest for the largest block 5 (see Tables 1 and 7).
- The annual average loads of TSS were found to increase by over four times under the 2040 full urban land use with high climate change (most conservative scenario) compared with that of today. The same increasing trend occurred for both TP and TN, with larger loads of over three times in future urban development for the high-climate scenario compared with the existing agricultural land use (Figure 7a,b). This is likely due to the very high rate of stormwater runoff generated in all future cases than the default initial concentrations of the pollutant loads for current and future land uses. Even though the initial mean storm flow concentrations of the pollutants were higher for agricultural land use compared with urban-mixed land use (Table 5), higher pollutant loadings are expected for future urban scenarios as a result of the significantly higher stormwater volume generated in the future.
- The wetlands were found to be efficient at removing TSS, TP, and TN and were in line with the objectives of the Urban Stormwater BPEMG [40] with target removal percentages of 80% for TSS, and 45% for nutrient loads for TP and TN (see Table 7). It can be observed from this table that wetlands, at worst, were able to retain over 90% of TSS, 77% of TP, and 52% of TN in all scenarios. The sizes of wetlands in blocks could be reduced from 2% of the block area to meet best practice stormwater management current guidelines.

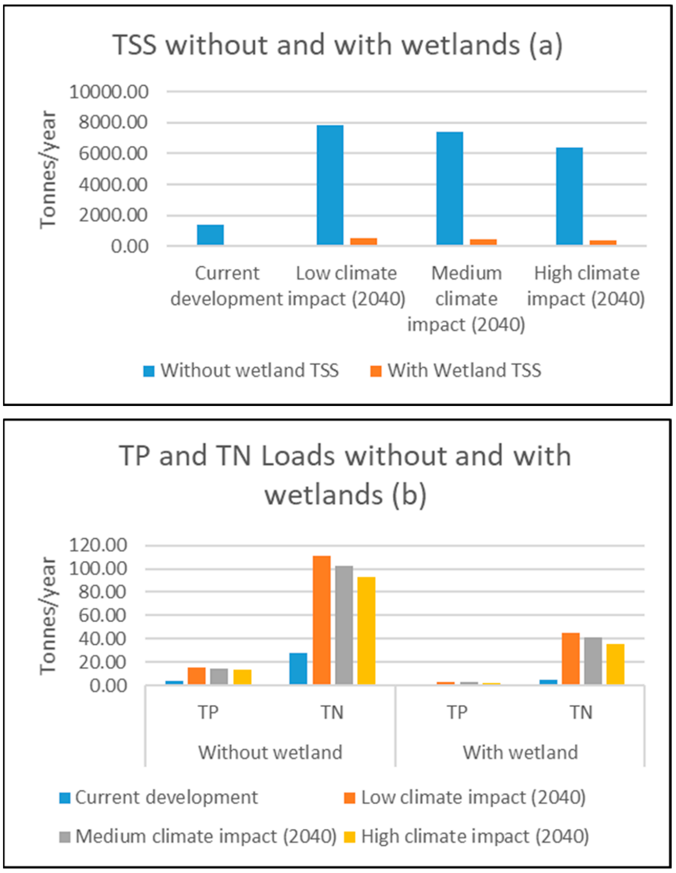

Figure 7. (**a**,**b**) Stormwater runoff quality TSS (**a**), TP, and TN (**b**) from development under various land use and climate change conditions.

Table 7. Annual average pollutant loadings for each block under various land-use and climatic conditions in the absence and presence of the wetlands, with their removal efficiency.

Development Condition & Climate Impact and Blocks (B)		TSS (Tons/Year)			TP (Tons/Year)			TN (Tons/Year)		
		Load without Weland	Load with Wetland	% Removal	Load without Wetland	Load with Wetland	% Removal	Load without Wetland	Load with Wetland	% Removal *
Existing Agricultural	B 1A	25.6	0.5	98.04	0.06	0.004	92.97	0.49	0.08	84.23
	B 1B	203.8	3.8	98.11	0.58	0.037	93.55	4.00	0.66	83.47
	B 2	240.7	5.1	97.87	0.75	0.050	93.32	5.19	0.85	83.68
	B 3	321.6	6.1	98.09	0.86	0.060	93.03	6.13	1.01	83.45
	B 4	172.7	3.4	98.05	0.47	0.032	93.00	3.51	0.56	83.91
	B 5	406.8	8.0	98.04	1.14	0.078	93.12	8.38	1.33	84.06
Future Urban Development—Low-Impact Climate Scenario	B 1A	131.7	12.4	90.55	0.28	0.06	77.53	1.89	0.90	52.33
	B 1B	1048.4	79.9	92.38	2.23	0.44	80.44	15.89	6.64	58.21
	B 2	1468.8	91.2	93.79	2.95	0.55	81.48	21.72	8.98	58.64
	B 3	1736.4	106.6	93.86	3.63	0.66	81.81	25.54	10.27	59.78
	B 4	954.3	73.2	92.33	1.91	0.38	80.18	13.26	5.59	57.80
	B 5	2484.3	134.5	94.58	4.58	0.83	81.90	32.90	13.07	60.29
Future Urban Development—Medium-Impact Climate Scenario	B 1A	128.29	12.1	90.60	0.25	0.06	77.57	1.84	0.85	53.97
	B 1B	1045.5	76.9	92.64	2.09	0.39	81.18	14.83	6.03	59.36
	B 2	1451.7	92.5	93.62	2.81	0.52	81.38	19.45	7.72	60.33
	B 3	1668.7	93.8	94.37	3.44	0.60	82.54	23.63	9.37	60.32
	B 4	904.7	60.5	93.32	1.77	0.33	81.35	12.71	5.19	59.14
	B 5	2186.0	134.2	93.86	4.42	0.76	82.84	30.41	12.07	60.28
Future Urban Development—High-Impact Climate Scenario	B 1A	112.8	8.7	92.24	0.23	0.04	80.12	1.66	0.72	56.56
	B 1B	918.4	56.2	93.87	1.93	0.34	82.53	13.07	5.09	61.03
	B 2	1160.8	63.1	94.56	2.55	0.43	83.05	17.92	6.85	61.80
	B 3	1510.3	78.8	94.78	2.92	0.48	83.39	21.28	8.05	62.18
	B 4	803.3	55.5	93.09	1.65	0.28	82.78	11.51	4.48	61.06
	B 5	1878.3	91.3	95.14	3.97	0.62	84.49	27.32	9.90	63.77

Note: (*) % removal of pollutant by wetlands is based on the loads with and without wetland provision in the blocks.

5. Conclusions

The overall objective of this investigation was to determine stormwater quantity and quality as an additional source for non-potable/portable applications in the Melton growth area under integrated water management approaches to meet the water demand of a newly planned development. The investigation explored a number of scenarios under changing land-use and climate conditions with and without the impact of the constructed wetlands. The stormwater quality investigations were limited to Urban Stormwater BPEM guidelines. Detailed investigations of wider water quality parameters are required for water treatment system design.

Modelling was based on 2040 conditions, considering full urban development of the Melton urban growth area and low, medium, and high-impact climate change scenarios. The conversion of land use from its existing agricultural use to a fully urbanised areas resulted in a remarkable increase in stormwater volume generated in the region. This increase in stormwater runoff volume was offset to some extent after the construction of wetlands due to significant ET losses happening in the wetlands. The hydrological modelling was based on local guidelines for various parameters due to the absence of catchment-specific stream flow data for model calibration and validation.

The modelling highlighted that the 8.39 GL/year of stormwater available today (if completely harvested) can contribute to meeting the required amount of potable and Class B recycled water (7.5 GL/year, reported by Greater Western Water). Under 2040 full urban land use and high climate impact, the provision of wetlands and 100% stormwater capture and treatment can generate 26.78 GL/year of potable water, which is more than the expected potable water demand of 23 GL/year.

The modelling with the provision of wetlands resulted in a considerable reduction in nutrient loads (minimum above 90% for TSS, 77% for TP, and above 52% for TN) compared with the untreated raw stormwater. It is suggested that the wetlands should be incorporated in the stormwater treatment train. To meet the water demand forecast at the Melton growth area and surrounding areas, the available stormwater in the region needs to be effectively captured, treated to an equivalent quality, and then pumped to the storage before usage. Moreover, harvested stormwater would require treatment through the combination of natural/engineered processes and appropriate advanced treatment trains to produce water reaching potable standards.

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