

Evaluating the potential for Blue-Green Infrastructure benefits using the case study of stormwater ponds in Cape Town, South Africa

Jessica Fell



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Abstract

A Water Sensitive City (WSC) is increasingly being pursued to deliver on various sustainability, resilience and liveability goals. Expanding Blue-Green Infrastructure (BGI) is a major step towards a WSC. BGI can provide multiple social and environmental benefits, from increased amenity to enhanced biodiversity to urban heat reduction. However, the expansion of BGI is not always feasible. This is particularly true in many Global South contexts with rapidly urbanising cities characterised by patterns of informality, inadequate infrastructure and service delivery provision, competition for space and increasing resource pressures. In such contexts, existing blue infrastructure (BI), i.e., natural or artificial water bodies such as rivers, canals, ponds, streams, wetlands and stormwater drainage provision, can be transformed to provide multiple benefits as BGI.

This study presents a multi-criteria analysis (MCA) methodology to evaluate the potential for existing BI to provide multiple benefits as BGI. The MCA methodology was developed through the case study of the City of Cape Town, South Africa. The multifunctional potential of the city's existing stormwater ponds, of which there are over 800, was evaluated. This was a contribution towards the city's 2020 Water Strategy commitment to '*become a Water Sensitive City*' by 2040 with multifunctional infrastructure. Using value-focused thinking, the MCA methodology incorporated seven benefits framed as WSC planning priorities: (1) 'Enhancing cultural and heritage associations with water systems', (2) 'Increasing water re-use', (3) 'Reducing the Urban Heat Island (UHI) effect', (4) 'Enhancing community services connections with water systems', (5) 'Increasing access to blue-green space', (6) 'Incorporating stormwater quality limitations', and (7) 'Enhancing biodiversity'. A pilot MCA was conducted to assist the process. An associated criterion was selected for each WSC planning priority through semi-structured interviews with WSC experts in Cape Town. The criteria were scored, and stakeholder weights were obtained using three weighting methods: rating, ranking and pairwise comparison. A weighted additive model was used to combine the scores and weights. Ponds with a high potential to provide a combination of the seven benefits were identified. The relative prioritisation of the ponds for the individual and combined criteria were mapped in a Geographic Information System (GIS) to allow for the visualisation of the rankings. Synergies and trade-offs were assessed using Pearson correlation coefficients between criterion scores.

In Cape Town, the 'Enhancing community services connections with water systems' WSC planning priority had the largest number of high scoring ponds, with 36% within 290 m of a school, community centre or religious institution. Of the ponds, 12% had a high potential for Managed Aquifer Recharge for 'Increasing water re-use'. This was largely because they overlaid a shallow sandy primary aquifer in the city. For 'Incorporating stormwater quality limitations', almost half of the ponds (46%) were within 200 m of a potentially contaminating activity (informal settlement, industrial, road, landfill, wastewater treatment works land cover). This indicated potential constraints to multifunctionality from poor stormwater quality.

Synergies between ‘Increasing water re-use’ and ‘Reducing the UHI’, ‘Enhancing community services connections with water systems’ and ‘Enhancing biodiversity’ were indicated through statistically significant positive correlations. This helps to identify ponds for strategic prioritisation to leverage co-benefits. However, negative correlations revealed the trade-offs that prioritising ponds for ‘Increasing access to blue-green space’ and ‘Increasing water re-use’ may not be well suited to ‘Incorporate stormwater quality limitations’. Stakeholders regarded the benefits of ‘Increasing access to blue-green space’ and ‘Increasing water re-use’ as the most important across the weighting methods. The combined criteria using the different weighting methods indicated a hotspot of ponds with the highest relative multifunctional potential in the southern central part of the city. These ponds would be the highest priority for multifunctional transformation to maximise benefits as BGI for a WSC.

The MCA methodology paired with GIS visual capabilities provides a strategic and participatory approach to evaluating the potential for existing BI to provide multiple benefits as BGI towards a WSC. Applying this methodology to Cape Town’s existing stormwater ponds illuminated their multifunctional potential. The MCA methodology is transferrable as the WSC planning priorities are relevant to many urban Global South contexts. It is flexible, able to incorporate different benefits, and the steps could be customised for different types of BI.

Acronyms

AHP	Analytic Hierarchy Process
BGI	Blue-Green Infrastructure
BI	Blue infrastructure
BMP	Best Management Practices
BSc	Bachelor of Science
CBD	Central Business District
CCT	City of Cape Town
CoP	Community of Practice
CRCWSC	Cooperative Research Centre for Water Sensitive Cities
GI	Green Infrastructure
GIS	Geographic Information System
GIS-MCDA	Geographic Information System multi-criteria decision analysis
LID	Low-impact development
MCA	Multi-criteria analysis
MCDA	Multi-criteria decision analysis
MAR	Managed Aquifer Recharge
NBS	Nature-based solutions
PCA	Potentially contaminating activity
PSS	Planning Support System
QGIS	Quantum Geographic Information System
RSA	South Africa
SuDS	Sustainable Drainage Systems/Sustainable Urban Drainage Systems
UHI	Urban Heat Island
UCT	University of Cape Town
UWMTF	Urban Water Management Transitions Framework
WCWSS	Western Cape Water Supply System
WSC	Water Sensitive City
WSUD	Water Sensitive Urban Design

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1. Introduction

1.1 Background to the research

Cities are faced with numerous water-related challenges. These range from rapid urbanisation to deteriorating water quality to climate change. The goal of becoming a Water Sensitive City (WSC) is increasingly being pursued to address these challenges and enhance urban sustainability, resilience and liveability (Wong *et al.*, 2020). A WSC offers an alternative systems-based approach to conventional centralised water management approaches¹ as it moves beyond the provision of water services to multifunctional water systems and enhanced biodiversity within liveable spaces (Brown *et al.*, 2008; Brown *et al.*, 2016). This is provided through physical infrastructure, institutional arrangements and social engagements.

Conventional centralised urban water infrastructure, management and planning approaches have been traditionally employed to deliver water supply, sanitation and drainage services. These approaches are usually highly engineered, reliant on technical experts and solutions, and generally comprise hard ‘grey’ infrastructure (Sivapalan *et al.*, 2012; Vörösmarty *et al.*, 2015). For example, increased stormwater runoff from urban impervious services is generally managed with hydraulically efficient, but ecologically damaging, concrete conduits (Walsh *et al.*, 2005). Viewed as a nuisance, stormwater has traditionally been managed separately from other urban water services, with flood protection as the sole function (Chocat *et al.*, 2007). While conventional centralised approaches have been successful for basic water services provision, they have many negative social, economic and environmental consequences (Gleick, 2003). Moreover, they are increasingly viewed as unable to address the expanded societal objectives for urban water systems (Wong & Brown, 2009; Montanari *et al.*, 2013; Savenije *et al.*, 2014; Capps *et al.*, 2016; Hoekstra *et al.*, 2018).

Blue-Green Infrastructure (BGI) is a major component of a WSC as it can provide multiple social and environmental benefits (Wong *et al.*, 2013; Ahmed *et al.*, 2019). BGI combines blue (surface water) and green (vegetated areas) infrastructure into an interconnected network that provides multiple functions. It comprises natural and designed landscape components, including green spaces and water bodies such as ponds, wetlands and restored water courses (Ghofrani *et al.*, 2017). BGI leverages natural processes and ecosystem services. Its defining characteristic of multifunctionality emphasises benefits such as improving water quality and security, increasing habitat and urban biodiversity and enhancing amenity (Drosou *et al.*, 2019). BGI can exist at different scales, from city to catchment to site, and can be new or retrofitted. Multifunctional systems are better equipped to address mounting pressures of urbanisation, climate and population changes, resource constraints, and stressed ecosystems (Benedict & McMahon, 2002; Meerow & Newell, 2019; Ashley *et al.*, 2022). A WSC with expanded BGI requires planning for

¹ For this thesis, conventional centralised approaches and systems refer to centralised water services provision, a professional culture of civil engineering and technical experts, technical solutions (e.g., pipe networks, sewers, treatment works, etc.), assumptions of stability and predictability, highly localised organisation structures and strong state regulation.

the often-elusive concept of multifunctionality and the associated provision of multiple benefits that are dependent on the local context (Kuller *et al.*, 2017). It necessitates integrated, strategic and flexible approaches to planning, with multiple disciplinary perspectives that can consider benefit synergies and trade-offs (Dominguez *et al.*, 2009; Meerow & Newell, 2017).

Constructing BGI in cities is difficult (Aleksejeva *et al.*, 2022). This is particularly true in Global South contexts with rapidly urbanising cities characterised by patterns of informality, competition for space, the poor state of infrastructure and service delivery provision, and increasing resource pressures (Fluhrer *et al.*, 2021; Pauleit *et al.*, 2021; Kumar *et al.*, 2023). However, it is sometimes possible to transform existing blue infrastructure (BI) into BGI (Uzomah *et al.*, 2014; Ahmed *et al.*, 2019; Fluhrer *et al.*, 2021). BI may be considered as the blue elements of BGI, i.e., natural or artificial water bodies such as rivers, canals, ponds, streams, wetlands and engineered stormwater drainage provision (Gunawardena *et al.*, 2017; Wu *et al.*, 2019). Swales, wetlands, engineered stormwater drainage systems (Viavattene *et al.*, 2008; Fenner, 2017; Ashley *et al.*, 2018; O'Donnell *et al.*, 2018) and stormwater ponds (Moore & Hunt, 2012; Fluhrer *et al.*, 2021; Mclachlan *et al.*, 2023; Tanyanyiwa *et al.*, 2023) have been proposed and evaluated for their potential to provide multiple BGI benefits.

Multi-criteria analysis (MCA) is widely used to evaluate potential for the provision of multiple BGI benefits (Lerer *et al.*, 2015; Di Matteo *et al.*, 2017; Kuller *et al.*, 2017; Meerow & Newell, 2017). MCA is flexible and able to incorporate multiple diverse objectives and criteria, as well as various options. It is multidimensional, participatory and sensitive to context (Dodgson *et al.*, 2009; Malczewski & Rinner, 2015; Dean, 2022). Participatory approaches to MCA are considered important to ensure the incorporation of stakeholder values. They can strengthen an MCA's quality, transparency and legitimacy (Dean, 2018). Value-focused thinking – focusing decisions through proactively considering fundamental principles – can be used to enhance strategic elements of an MCA (Keeney, 1994, 1996). MCA has the capacity to incorporate contextual Global South factors.

The City of Cape Town (CCT), South Africa (RSA) has committed to '*become a Water Sensitive City*' by 2040 through its 2020 Water Strategy (City of Cape Town, 2020b), although it is grappling with the associated planning and implementation. The CCT is socio-economically unequal and spatially segregated, and faces typical urban Global South challenges including high degrees of informality, colonial legacies, weak planning and institutional capacity, competition for land, outward expansion, deteriorating water infrastructure and unplanned and unregulated growth (Taing *et al.*, 2019; Ziervogel, 2019; Scheba *et al.*, 2021; Western Cape Government, 2021). The CCT's commitment to the approximately 4.8 million citizens in 2021 emphasises the optimal use of stormwater for flood control, aquifer recharge, ecological enhancement, water re-use and recreation with multifunctional infrastructure (Western Cape Government, 2021). It followed one of the CCT's worst droughts and the associated 'Day Zero' crisis which forecast the day when the taps would effectively run dry (Ziervogel, 2019). The drought was caused largely by below average rainfall over 2015 to 2017 which might well be linked to climate change (Otto *et al.*, 2018; Wolski *et al.*, 2020). The CCT has been engaging with the WSC concept in

policy and planning for over a decade and thus provides a suitable case study for the development of an MCA methodology to evaluate the potential for existing BI to provide multiple benefits as BGI towards a WSC (Carden & Fell, 2021; Mguni *et al.*, 2022).

In RSA, engagement with the WSC concept formally commenced with the 2014 publication of ‘Water Sensitive Urban Design² for South Africa: Framework and Guidelines’ (Armitage *et al.*, 2014). The publication adapted and translated the concept that had already been established elsewhere (Australia, Singapore, etc.) for the South African context. It was commissioned by the South African Water Research Commission (WRC) with the work undertaken by the Urban Water Management Group, now the Future Water Institute, at the University of Cape Town (UCT). Around the same time, guidelines on Sustainable Drainage Systems (SuDS) (Armitage *et al.*, 2013) were developed and a Community of Practice (CoP) (Carden *et al.*, 2016) was formed. Water sensitive spatial planning guidelines then followed (Fourie *et al.*, 2020a, 2020b). However, planning for a WSC in a Global South context such as RSA presents many complex challenges (Mguni *et al.*, 2022).

The Future Water Institute at UCT has continued WSC-related research. This included an interdisciplinary project titled ‘Pathways to water resilient South African cities’, which began in 2020 and is scheduled to end in 2025. The project is a partnership with the University of Copenhagen, Denmark. It has proposed using the CCT’s existing stormwater ponds, of which there are over 800 (City of Cape Town, 2019l). They were primarily designed for stormwater management alone, but many are arguably underutilised and have potential to provide additional benefits as BGI, thus assisting the CCT in becoming a WSC (Rohrer, 2014).

1.2 Aims and research questions

This study aims to develop an MCA methodology to evaluate the potential for existing BI to provide multiple benefits as BGI. This is done through the case study of the existing stormwater ponds in Cape Town, RSA as part of its commitment to become a WSC. The research questions were:

- How can value-focused thinking be used to identify BGI and WSC benefits to be used as MCA objectives?
- What relevant contextual criteria may be used to measure the achievement of these objectives?
- What are the synergies and trade-offs between different benefits?
- Can incorporating stakeholder input in a participatory MCA enhance WSC planning?
- What does the application of the MCA methodology to Cape Town’s stormwater ponds

² Water Sensitive Urban Design (WSUD) is often used in parallel with the term WSC, however there are differences between the two; WSC describes the objective, while WSUD describes the process (Fletcher *et al.*, 2015). This research uses the framing of the vision of a WSC.

reveal about their multifunctional potential?

The research contribution is envisaged as twofold:

- (1) the development of an MCA methodology to evaluate the potential for existing BI to provide multiple benefits as BGI towards a WSC, through the case study of Cape Town, RSA. The MCA methodology developed is strategic, flexible, participatory and transferrable.
- (2) the outputs and insights obtained from applying the MCA methodology to Cape Town's existing stormwater ponds.

1.3 Thesis layout

This thesis is comprised of ten chapters:

Chapter 1, this chapter, provides background to the research, the research focus and the anticipated contribution.

In Chapter 2, a literature review provides guidance on two key areas for the research: (1) the concepts of WSCs and BGI, and associated planning, with specific attention to urban Global South contexts, and (2) MCA methods and key steps, with examples from BGI planning to explain each step.

Chapter 3 outlines the overall research process of developing the key MCA steps. The initial MCA step of identifying and structuring WSC objectives is presented. Seven objectives representing WSC benefits are identified from the literature and structured as WSC planning priorities.

The case study of Cape Town, RSA is introduced in Chapter 4. It starts with a general description of the city and its water management and planning approaches and other challenges. The history of the city's engagement with the WSC concept in planning and practice is then presented, including the commitment to become a WSC by 2040.

Chapter 5 selects the BI option of existing stormwater ponds in Cape Town, of which there are over 800, as the example to be used for this research. The process of obtaining and refining a stormwater ponds dataset is described.

Chapter 6 presents a pilot MCA with Cape Town's stormwater ponds used to refine the WSC planning priorities, inform the criteria and guide stakeholder input for the final MCA.

The semi-structured interviews conducted with seven WSC experts are discussed in Chapter 7. The interviews provided specific input on selecting relevant contextual criteria and datasets and more general input for the final MCA.

Chapter 8 presents the selection of criteria organised under the WSC planning priorities,

the acquisition and processing of associated datasets, performance scoring and assessing synergies and trade-offs for the final MCA.

In Chapter 9, the stakeholder derived weightings are described and the combination of the scores and weights to produce the stormwater pond multifunctional potential rankings is presented for the final MCA. This is followed by a discussion which covers the final MCA and insights from the process of developing the MCA methodology.

Chapter 10 presents the conclusions and recommendations for further research.

1.4 Aligned research

This research is aligned to an interdisciplinary project titled ‘Pathways to water resilient South African cities’ undertaken by UCT’s Future Water Institute and the University of Copenhagen, Denmark. The overall project objective is to identify opportunities and generate knowledge on the physical and institutional integration of BGI into South African cities that will support and accelerate a transition towards water resilience. The project has three work packages: (1) physical experiments, (2) governance processes for enabling emergent transitions, and (3) implementation and dissemination of generated knowledge. The physical experiments involve transforming an existing stormwater detention pond in a previously socio-economically disadvantaged neighbourhood in Cape Town for multifunctionality including Managed Aquifer Recharge (MAR) and enhanced amenity, liveability and biodiversity. Various site and laboratory experiments have generated knowledge on treating polluted stormwater, MAR infiltration rates, groundwater dynamics and developing low-cost methods for transforming stormwater ponds. The governance and social processes include extensive consultation through structured and semi-structured interviews, workshops, visual harvesting for a mural, surveys and WhatsApp group chat analyses with residents around the stormwater pond as well as city officials.

The research also aligns with the ‘Benchmarking the City of Cape Town as a Water Sensitive City’ project commissioned by the Western Cape Government: Department of Environmental Affairs and Development Planning and the City of Cape Town Metropolitan Municipality. This was undertaken from 2020 to mid-2021 by Zutari (Pty) Ltd, in partnership with UCT’s Future Water Institute and the Cooperative Research Centre for Water Sensitive Cities (CRCWSC), Melbourne, Australia. This benchmarking project was one of the first steps towards operationalising the CCT’s commitment to ‘*become a Water Sensitive City*’ by 2040 and involved the application of the ‘Water Sensitive City Index’ to benchmark Cape Town’s current performance against seven goals of a WSC. The ‘Water Sensitive City Index’ was adapted for the South African context by rating 16 out of the 34 indicators separately for formal and informal areas of a city to acknowledge the inequalities between these areas (Figure 2). The author was an embedded researcher for the project. The ‘Water Sensitive City Index’ goals and indicators, extensive stakeholder engagement (involving over 50 key selected stakeholders over three workshops) and project results provided context for this research.



Figure 1: The transformed stormwater pond (left) and a section of the mural (right)
(Carden, 2023)

Socio-Political Goals				Bio-Physical Goals		
1. Ensure good water sensitive governance	2. Increase community capital	3. Achieve equity of essential services	4. Improve productivity and resource efficiency	5. Improve ecological health	6. Ensure quality urban space	7. Promote adaptive infrastructure
1.1 Knowledge, skills and organisational capacity	2.1 Water literacy	3.1 Equitable access to safe and secure water supply	4.1 Benefits across other sectors because of water-related services	5.1 Healthy and biodiverse habitat	6.1 Activating connected pleasant urban green and blue space	7.1 Diverse fit-for-purpose water supply system
1.2 Water is key element in city planning and design	2.2 Connection with water	3.2 Equitable access to safe and reliable sanitation	4.2 Low GHG emissions in water sector	5.2 Surface water quality and flows	6.2 Urban elements functioning as part of the urban water system	7.2 Multi-functional water system infrastructure
1.3 Cross-sector institutional arrangements and processes	2.3 Shared ownership, management and responsibility of water assets	3.3 Equitable access to flood protection	4.3 Low end-user potable water demand	5.3 Groundwater quality and replenishment	6.3 Vegetation coverage	7.3 Integration and intelligent control
1.4 Public engagement, participation and transparency	2.4 Community preparedness and response to extreme events	3.4 Equitable and affordable access to amenity values of water-related assets	4.4 Water-related business opportunities	5.4 Protect existing areas of high ecological value		7.4 Robust infrastructures
1.5 Leadership, long-term vision and commitment	2.5 Culture, heritage and first nations involvement in water planning		4.5 Maximised resource recovery			7.5 Infrastructure and ownership at multiple scales
1.6 Water resourcing and funding to deliver broad societal value						7.6 Adequate maintenance
1.7 Equitable representation of perspectives						

16

 Formal/Informal

18

 City-wide

Figure 2: The adapted ‘Water Sensitive City Index’ (Zutari, 2020b)

2. Literature review

This chapter presents a review of the literature for the two key areas for this research. The first is on WSCs and BGI, and their associated planning. Various supportive frameworks for planning WSC systems, which emphasise MCA, are discussed. Specific attention is given to urban Global South contexts in general, with a section detailing the history of WSCs in RSA. The second key focus of the literature review is on MCA and the various associated methods. The key MCA steps are described and explained with examples from WSC and BGI planning and evaluation literature.

2.1 The shift to water sensitivity

Water is an integral component of the urban setting. A safe and secure water supply, along with sanitation and drainage for public hygiene and flood protection, has always ranked high among the primary needs of urban dwellers (Delleur, 2003). The pursuit and delivery of these needs over time shaped the conventional centralised urban water systems and management approaches that still dominate today (Brown *et al.*, 2009). A conventional water supply usually relies on large, centralised storage, conveyance and treatment infrastructure and a single water source, such as surface water. Drainage and sanitation similarly rely on large end-of-pipe infrastructure in the form of combined or separate sewers (Delleur, 2003). Cities with older drainage systems still rely on combined sewers, however separate sewers are now the most common (Butler & Davies, 2011). In this water management paradigm, drinking water appears, and wastewater and stormwater disappears (Gleick, 2003). The paradigm is characterised by centralised provision, mono-functional infrastructure, a professional culture of civil engineering and technical experts, assumptions of stability and predictability, a narrow set of values for planning and decision making and strong state regulation. Truffer *et al.* (2010) describes the strong path-dependencies of this paradigm, and the planning and decision making approaches that perpetuate conventional infrastructure investments – defined by Walker (2000) as an ‘entrapment’ or ‘lock-in’ phenomenon. As Hohenberg & Lees (1985) note, urban structures are long-lived affairs.

Conventional approaches to drainage consider stormwater as a nuisance to be removed as fast as possible to minimise disturbance to urban activities. Stormwater infrastructure usually takes the form of a network of hidden or below-ground concrete lined pipes which rapidly convey water – and associated pollutants from urban areas – in the most hydraulically efficient manner (Fletcher *et al.*, 2015). Stormwater is traditionally managed apart from other urban water services with the sole initial function of flood protection and, more recently, environmental management (Chocat *et al.*, 2007). A major problem with these stormwater systems, along with their wasteful nature and inadequacy for the developing world, is poor water quality (Chocat *et al.*, 2007). Walsh *et al.* (2005) describes the urban stream syndrome, whose symptoms include increased flows and runoff, flashier hydrographs and deteriorated water quality associated with the urban impervious surfaces and artificial drainage. The syndrome often manifests differently in

developing countries because of the patterns of development and the multifunctional role of streams as water sources, providers of ecosystem services and conveyers of waste (Capps *et al.*, 2016).

Conventional approaches have certainly provided immediate benefits for billions of urban dwellers. Particularly in the Global North, they have addressed the targeted problems of water supply, public health and flood risk protection (Gleick, 2003). However, they have been accompanied by many adverse social, economic and environmental consequences (Wong & Eadie 2000; Brown 2005; Wong & Brown 2008; Barbosa *et al.* 2012). The objectives of urban water systems have also now expanded to include resilience, equity and liveability. Consequently, the ability of conventional centralised approaches to respond to the expanded societal objectives for water systems, mounting global pressures of climate and population changes, resource constraints, and stressed ecosystems is increasingly and widely doubted (Wong & Brown, 2009; Montanari *et al.*, 2013; Savenije *et al.*, 2014; Capps *et al.*, 2016; Hoekstra *et al.*, 2018).

2.2 Water Sensitive Urban Design and Water Sensitive City principles

Water Sensitive Urban Design (WSUD) and WSCs offers an alternative systems-based approach to conventional centralised urban water management and planning. The concepts of WSUD and WSC emerged in Australia in the 1990s, through professionals such as Whelans *et al.* (1994) and Mouritz (1996). They were expanded on and formalised by the CRCWSC in the 2000s (Fletcher *et al.*, 2015). The concepts emerged in response to challenges facing cities including rapidly growing urban populations, changing population dynamics, environmental degradation, climate change, and an increasing global focus on sustainability (Brown *et al.*, 2009). From an initial association with stormwater, WSUD and WSCs have evolved to encompass all aspects of integrated urban water cycle management and planning, including water supply, sewerage and stormwater.

WSUD is often used in parallel with the term WSC. However, there are differences between the two; WSC describes the destination (the objective), while WSUD describes the process (Fletcher *et al.*, 2015). The WSC concept is inherently broad, and an idealised WSC comprises multiple objectives, many of which are at the level of academic and policy rhetoric (Wong & Brown, 2009). The visionary WSC state is more of a qualitative concept rather than a precise state that can be scientifically measured.

A WSC intentionally plans for sustainability, resilience, productivity and liveability through a combination of physical infrastructure, governance arrangements and social engagement. Brown *et al.* (2016) explain that a WSC seeks to protect and enhance the health of receiving waterways, reduce flood risk, and create public spaces that harvest, clean, and recycle water. It advocates ‘fit-for-purpose’ water use, i.e., use appropriate to the water quality, and

delivery of water through both centralised and decentralised multifunctional infrastructure. Table 1 provides a comparison of the attributes of traditional paradigms, i.e., current centralised water systems, and the sustainable regime of a WSC (Keath & Brown, 2009). Figure 3, adapted from Hoban & Wong (2006), visualises the natural water balance and the urban water balance, showing the impacts of urbanisation on the water cycle, and the WSC urban balance.

Table 1: A WSC compared to current traditional paradigms (Keath & Brown, 2009)

Attributes	Traditional regime	Sustainable regime
System boundary	Water supply, sewerage and flood control for economic and population growth and public health protection.	Multiple purposes for water considered over long-term timeframes including waterway health and other sectoral needs i.e., transport, recreation/amenity, micro-climate, energy, etc.
Management approach	Compartmentalisation and optimisation of single components of the water cycle.	Adaptive, integrated, sustainable management and planning of the total water cycle (including land use)
Expertise	Narrow technical and economic focused disciplines.	Interdisciplinary, multistakeholder learning across social, technical, economic, design, ecological spheres, etc.
Service delivery	Centralised, linear, and predominantly technologically and economically based.	Alternative, flexible solutions at multiple scales via a suite of approaches with multiple functions (technical, social, economic, ecological, etc).
Role of public	Water managed by government on behalf of communities.	Co-management of water between government, business, and communities.
Risk	Risk regulated and controlled by government.	Risk shared and diversified via private and public instruments.

There are three WSC pillars (Wong & Brown, 2009): (1) Cities as water supply catchments: access to a diversity of water sources underpinned by a diversity of centralised and decentralised infrastructure, (2) Cities providing ecosystem services: provision of ecosystem services for the built and natural environment, and (3) Cities comprising water sensitive communities: socio-political capital for sustainability and water sensitive decision making and behaviours.

The three WSC pillars were adapted and expanded upon by Binney *et al.* (2010) to include four themes and twelve principles for a City of the Future (Figure 4). One of the key features of a WSC is proactive, strategic and collaborative spatial planning with multiple disciplines and sectors involved. The visionary features are: (1) harmony between water planning and urban planning, (2) adaptive and multifunctional infrastructure, and (3) productive and ongoing collaborations between science, policy, practice and community (Brown *et al.*, 2009; Wong & Brown, 2009; Ferguson *et al.*, 2013).



Figure 3: The attributes of a hypothetical WSC (Zutari, 2020b)

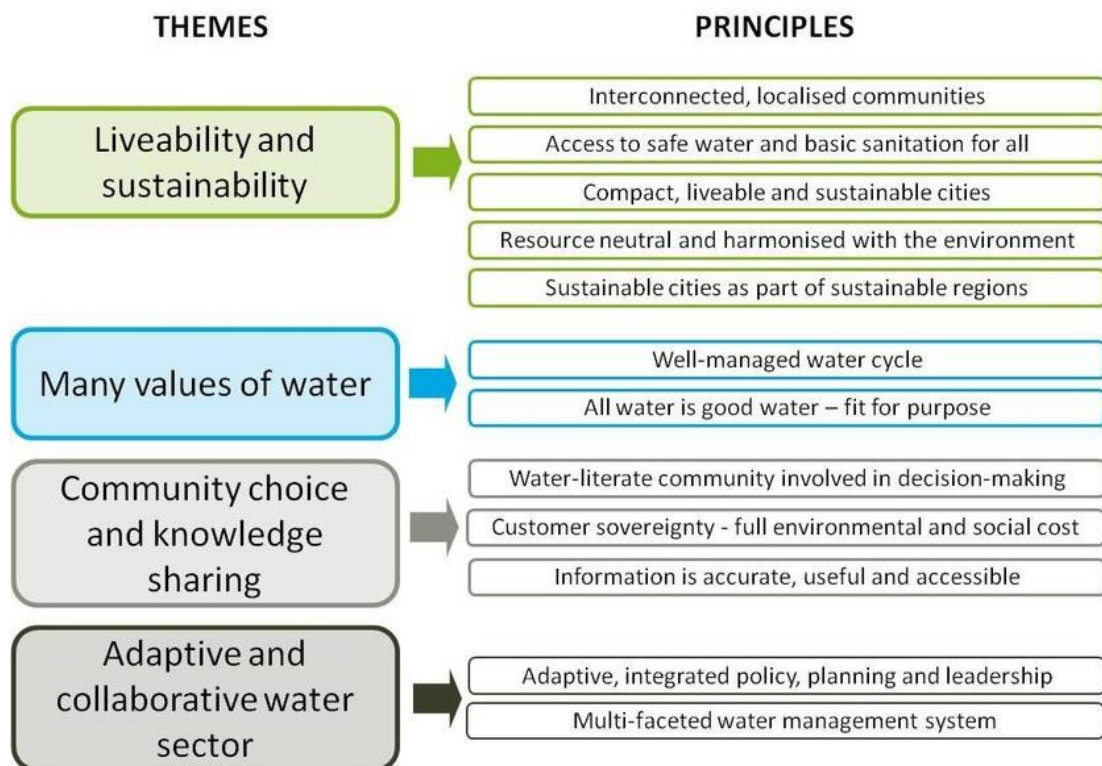


Figure 4: The four themes and 12 principles for a City of the Future (Wong *et al.*, 2013)

The transition to a WSC can be measured with the aid of the Urban Water Management Transitions Framework (UWMTF), developed by Brown *et al.* (2009) (Figure 5). The framework presents a typology of six distinct developmental city states in the evolution of urban water management from the ‘Water Supply City’ to the ‘WSC’ in a nested continuum. The dominant socio-political drivers and service delivery functions of each state are described. As a city moves from one state to the next, particularly from a ‘Drained City’ onwards, the hydro-social contract undergoes significant changes. The first three city states (the water insensitive city states) provide basic water, sanitation and stormwater drainage services. The subsequent states (the WSC states) provide additional benefits such as amenity, environmental protection and multifunctional infrastructure. These changes require transformative planning and management approaches (Wong & Brown, 2009).

The UWMTF has been used to develop a ‘Water Sensitive City Index’ (Figure 6). The index benchmarks a city’s current water sensitive performance against seven goals and 34 corresponding indicators of a WSC (Brown *et al.*, 2016). The goals of a WSC are categorised into socio-institutional and biophysical. The socio-institutional goals encompass the social, institutional, political, and overall enabling context of the city, which includes the people, systems, processes and cultures (Goals 1, 2, and 3). The biophysical goals refer to the physical context and on-ground outcomes of a WSC (Goals 4, 5, 6 and 7).

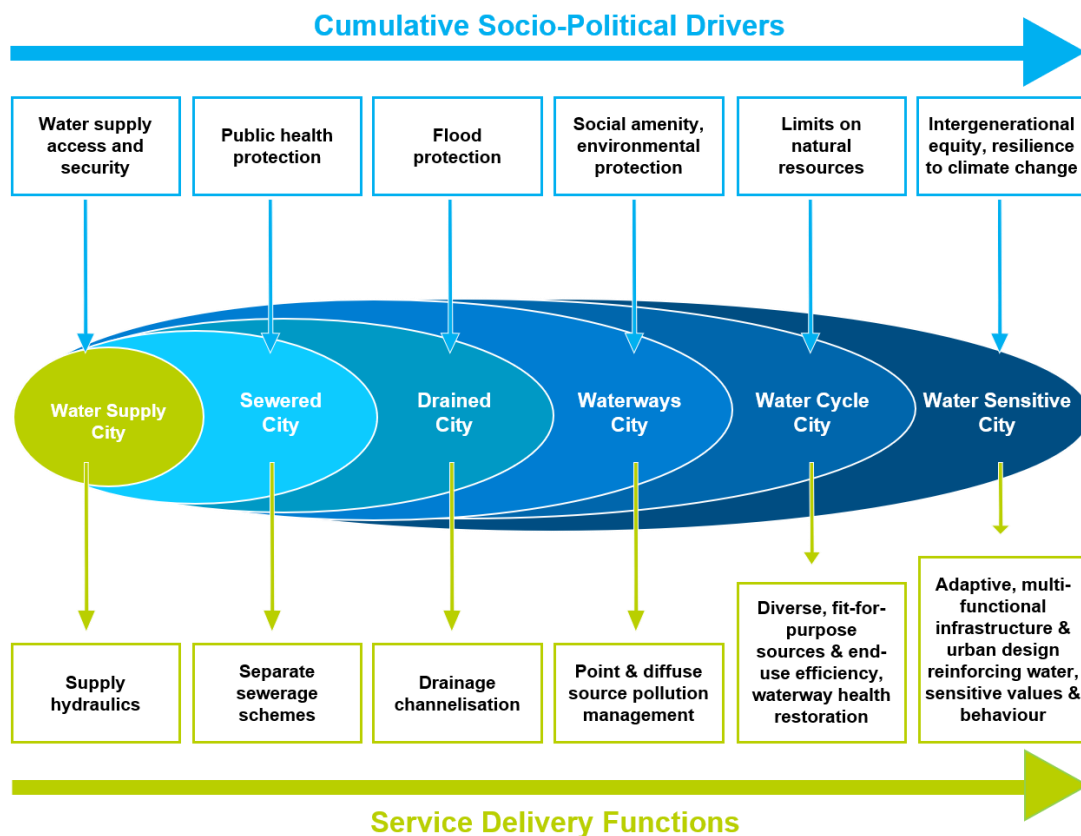


Figure 5: The Urban Water Management Transitions Framework (Wong *et al.*, 2020)

1. Ensure good water sensitive governance	2. Increase community capital	3. Achieve equity of essential services	4. Improve productivity and resource efficiency	5. Improve ecological health	6. Ensure quality urban space	7. Promote Adaptive infrastructure
1.1 Knowledge, skills and organisational capacity	2.1 Water literacy	3.1 Equitable access to safe and secure water supply	4.1 Benefits across other sectors because of water-related services	5.1 Healthy and biodiverse habitat	6.1 Activating connected urban green and blue space	7.1 Diverse fit-for-purpose water supply system
1.2 Water is key element in city planning and design	2.2 Connection with water	3.2 Equitable access to safe and reliable sanitation	4.2 Low GHG emissions in water sector	5.2 Surface water quality and flows	6.2 Urban elements functioning as part of the urban water system	7.2 Multi-functional water system infrastructure
1.3 Cross-sector institutional arrangements and processes	2.3 Shared ownership, management and responsibility of water assets	3.3 Equitable access to flood protection	4.3 Low end-user potable water demand	5.3 Groundwater quality and replenishment	6.3 Vegetation coverage	7.3 Integration and intelligent control
1.4 Public engagement, participation and transparency	2.4 Community preparedness and response to extreme events	3.4 Equitable and affordable access to amenity values of water-related assets	4.4 Water-related commercial and economic opportunities	5.4 Protect existing areas of high ecological value		7.4 Robust infrastructure
1.5 Leadership, long-term vision and commitment	2.5 Indigenous involvement in water planning		4.5 Maximised resource recovery			7.5 Infrastructure and ownership at multiple scales
1.6 Water resourcing and funding to deliver broad societal value						7.6 Adequate maintenance
1.7 Equitable representation of perspectives						

Figure 6: The ‘Water Sensitive City Index’ (Brown *et al.*, 2016)

2.3 Blue-Green Infrastructure

BGI is an embedded component of a WSC. It can be viewed as an infrastructure-based means to reach the visionary end goal of a WSC. It is increasingly embraced around the world as a component of a WSC in line with expanded societal objectives for urban water systems of resilience, sustainability and liveability. Multifunctional systems are better equipped to address mounting global pressures of climate and population changes, resource constraints, and stressed ecosystems (Ghofrani *et al.*, 2017; Liao, 2017; O’Donnell *et al.*, 2021). The provision of multiple benefits is important in urbanising cities with competition for space. It is particularly relevant in challenging Global South contexts where there are increasing urban dwellers who require more services from limited budgets and resources.

BGI is defined by O’Donnell *et al.* (2021) as ‘*an interconnected network of landscape components, both natural and designed, that includes open, green spaces and water bodies (ephemeral, intermittent and perennial) which provide multiple functions*’. It combines blue (surface water) and green (vegetated areas) infrastructure. The green elements of BGI include open and green spaces. BI is the blue elements of BGI, i.e., natural or artificial water bodies such as rivers, canals, ponds, streams, wetlands and stormwater drainage provision (Gunawardena *et al.*, 2017; Wu *et al.*, 2019). It includes permanent and temporary surface water and inland and coastal water bodies. BI comprises running as well as standing water bodies and can be created and/or managed to provide ecosystem services (Ioja *et al.*, 2021).

Examples of BGI systems include green roofs and walls, swales, rain gardens, street trees,

ponds, urban wetlands, restored watercourses, reconnected floodplains, and re-naturalised and de-culverted rivers. Figure 7 illustrates potential components of BGI that can provide various benefits from a practical example in the Netherlands (Ghofrani *et al.*, 2017). BGI can be used to retain, attenuate, store and re-use surface water. It leverages natural processes and ecosystem services. The concept is linked to soil and bioengineering approaches where plants play a prominent role. It can exist at different scales from city to catchment to site.

BGI can operate at various planning levels and contexts including urban, peri-urban and regional. It can be new or retrofitted. BGI can be comprised of constructed elements and/or natural elements – which is particularly useful in densifying urban areas. For example, Fluhrer *et al.* (2021) describes the integration and combination of existing green spaces or infrastructure with other urban infrastructures such as drainage, transport and buildings. Retrofitting drainage systems such as retention and detention ponds and pavements (Uzomah *et al.*, 2014), and transforming existing unvegetated roofs to green roofs (Venter *et al.*, 2021; Aleksejeva *et al.*, 2022) are also options.

Networks and connectivity are emphasised within the BGI concept. BGI can play an important role in flooding and extreme weather events, with water bodies serving the purposes of water storage, regulators of river systems, biodiversity habitats and conservation, cleaning systems of polluted water, areas for the growth of productive wetland crops, for example reeds for biofuel, and spaces for amenity (Ghofrani *et al.*, 2017).

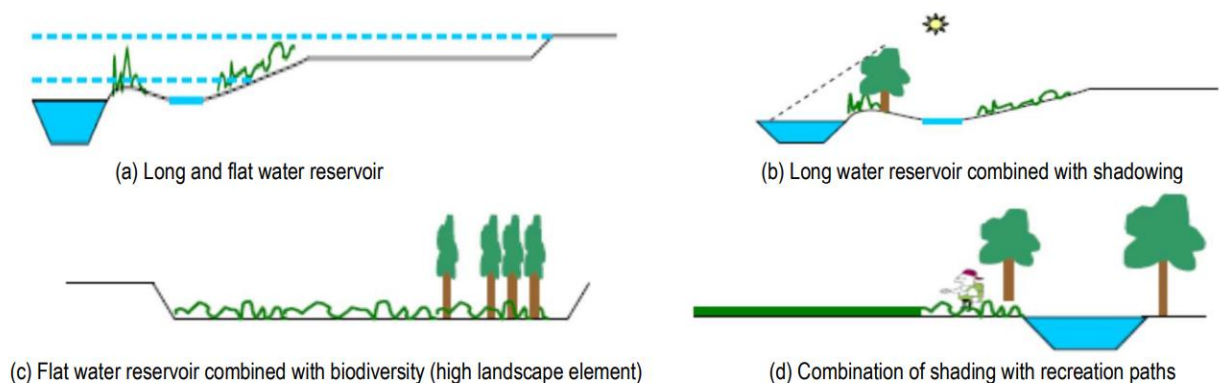


Figure 7: Potential components of BGI (Ghofrani *et al.*, 2017)

Central to the concept is the ability of BGI to provide multiple economic, environmental and social benefits. Multifunctionality is explicitly and strategically planned for, rather than being a product of chance (Hansen & Pauleit, 2014). The multiple benefits that can be delivered have been written about extensively in the literature and include urban temperature regulation, improving air quality, reducing surface water flooding, improving water security and water quality, MAR, noise reduction, carbon storage, habitat and urban biodiversity, pollination, provision of community food, Urban Heat Island (UHI) reduction, uplift in property value adjacent to blue-green space, improving physical and mental health and well-being, providing

cultural services, enhanced amenity and recreational opportunities, supporting positive placemaking and extending the service life of ageing grey infrastructure through retro-fitting (Ghofrani *et al.*, 2017; Wentworth, 2017; O'Donnell *et al.*, 2021). The benefits or functions of BGI are often categorised according to the ecosystem services of supporting, provisioning, regulating and cultural. The general categories of biophysical, social, ecological, economic, institutional and planning are also used.

BGI is a relatively new term, however, the principles and practices are not new and are linked to the concepts of WSCs, WSUD, SuDS, Low-impact development (LID), Best Management Practices (BMPs), Nature-based solutions (NBS) and Green Infrastructure (GI). BGI is closely related to and emerged from the concept of GI (Mell, 2008; Hansen & Pauleit, 2014). A comprehensive definition of GI put forward by Benedict & McMahon (2002) is: '*Green Infrastructure is an interconnected network of waterways, wetlands, wildlife habitats, and other natural areas; greenways, parks, and other conservation lands; working farms, ranches, and forests; and wilderness and other open spaces that support species, maintain natural ecological processes, sustain air and water re- sources, and contribute to the health and quality of life for (American) communities and people*'.

2.4 Water Sensitive City planning

The transition to a WSC requires strategic planning. An enormous shift in a city is needed to move from conventional centralised approaches to water sensitive approaches. This necessitates transformative and visionary planning that embraces flexibility, complexity and diversity (Ferguson *et al.*, 2013). In comparison to the long history and experience associated with planning conventional centralised approaches, there is still relatively limited – but growing – experience with WSC planning. A WSC often includes a greater number of multifunctional measures that require more physical space. This poses new challenges for planners and necessitates the involvement of multiple disciplines, rather than just engineering (Dominguez *et al.*, 2009). The range of environmental, social and economic benefits that can be provided can be difficult to measure and value (Ashley *et al.*, 2022).

The functions and benefits of WSC systems and technologies, including BGI, are often highly localised (Ashley *et al.*, 2018). WSC systems are intended to be an integrated part of the urban fabric. There are feedbacks between the system and the biophysical, socio-economic and governance landscape – the systems' location impacts its functioning, and the system also affects the function and quality of its surroundings (Rijke *et al.*, 2008; Lerer *et al.*, 2015; Kuller *et al.*, 2017). The vision and manifestation of a WSC is context specific. City specific factors need to be considered in planning processes such as the biophysical environment, ecology, climate, history, urbanisation patterns, geography, demography, existing technologies, and governance and institutional structures (Brown *et al.*, 2016).

WSC planning in the Global South presents a set of complex and unique challenges largely linked to urbanisation characteristics. The Global South will see the majority of future

urbanisation, with an estimated 93% of urban growth from 2011 to 2050 to occur in Africa, Asia and Latin America (Zhang, 2016). In Africa, urbanisation has historically been in the form of small- and medium- sized cities but this is changing as cities grow and densify (Satterthwaite, 2016; Dodman *et al.*, 2017). Many African cities are rapidly sprawling and densifying as they consist of single storey crowded informal settlements. For example, approximately 70% of the urban population in Africa live in unplanned and dense peri-urban or urban informal settlements (Zhang, 2016; Baeumler *et al.*, 2021). Informal densification should not be confused with the density associated with positive policy goals including efficiency, inclusivity, resilience and liveability. Nor should it be confused with the aspirations of the compact city movement (Hansen *et al.*, 2019). Pauleit *et al.* (2021) elaborate on the salient characteristics of African urbanisation that need to be considered during WSC planning as high degrees of informality, colonial legacies, weak planning, institutional and governance capacity and institutions, competition for land, outward expansion, deteriorating infrastructure and unplanned and unregulated growth.

In an Indian context, Kumar *et al.* (2023) note that large and unplanned cities with inadequate infrastructure including roads and drainage, low municipal budgets, reduced institutional capacities, and misrecognition of citizenship present challenging conditions for water sensitive planning. The authors posit that assumptions for water sensitive planning in the Global North do not hold true for the Global South. Notably, that sewerage and drainage is planned and built prior to residents moving into their dwellings. In RSA, planning challenges for a WSC transition include institutional and planning fragmentation with siloed institutional arrangements, power dynamics within local authorities and a mindset of lack of resources and time constraints. The traditional planning and engineering paradigm is also not suited to current complex water issues, and there is an overall resistance to change in municipalities responsible for water service provision (Fisher-Jeffes *et al.*, 2012).

‘Leapfrogging’ is posited as an enabler and beneficial policy goal for Global South cities to plan for a transition to WSCs. It is positioned as a way to skip the less desirable states and consequences of the water insensitive city states. Using the concept of leapfrogging, Global South cities may be able to adopt visionary planning processes that proactively and strategically incorporate various WSC benefits. Brodnik *et al.* (2018) state that ‘...*the concept of leapfrogging suggests that undesirable conditions that increase levels of pollution and vulnerability can be bypassed to reach the more desirable sustainable and resilient conditions. Cities in developing countries are particularly well positioned to take these leaps forward because less resources have been invested in traditional urban water management infrastructure and institutions which makes them more receptive to water sensitive practices*’. However, leapfrogging has been criticised as a simplistic and idealistic concept (Tórrez, 2021). Enabling factors for leapfrogging are highly context specific and dependent on policy and institutional arrangements. The concept of leapfrogging is often unable to adequately incorporate various social equity and practical issues (Gleason & Flores, 2021).

In the South African context, Armitage *et al.* (2014) note that it is difficult to address sustainability in water management when a large proportion of the population lack access to basic

water supply, sanitation and drainage. In an urban Mexican context, the governance system was unable to support leapfrogging, with barriers were as conventional locked-in approaches, lack of long-term planning and insufficient policy coherence (Flores *et al.*, 2019). Particularly in informal settlements, or urban landscapes with various degrees of informality, it may not be appropriate to implement WSC interventions without first addressing basic service provision and the functionality of existing grey infrastructure (Fisher-Jeffes *et al.*, 2017a). Armitage (2011) warns that *‘the failure, for example, to comprehend that every drop of water brought into an informal settlement has to be safely removed otherwise it becomes a drainage problem and thus a possible health threat borders on criminal’*. Using the concept of leapfrogging for strategic WSC planning needs to be accompanied by caution in the face of these complexities, while also incorporating the positive benefits of developing visionary goals.

Planning for a WSC, particularly in a Global South context, can be classified as a ‘wicked’ problem (Kuller *et al.*, 2017). Rittel & Webber (1973) outline 10 defining characteristics of wicked problems:

- (1) they have no definitive formulation, with the information needed to understand the problem depending on the decision maker’s approach for solving the problem,
- (2) they have no stopping rule, that is, there is no way to tell when ‘the’ or ‘a’ solution has been found,
- (3) their solutions are not true-or-false but good-or-bad; there are multiple and conflicting criteria for defining solutions, there are no conventionalised criteria for objectively deciding whether a solution is correct or false,
- (4) there is no immediate or ultimate test of a solution; any solution has multiple feedback loops,
- (5) every solution is a one-shot operation, every attempt counts significantly,
- (6) they do not have an enumerable or an exhaustively describable set of potential solutions,
- (7) they are essentially unique,
- (8) they can be considered as a symptom of another wicked problem,
- (9) a discrepancy representing a wicked problem can be explained in numerous ways, with the choice of the explanation determining the nature of the problem’s resolution, and
- (10) the planner has no right to be wrong, as ‘the’ solution is not to find a truth but to improve some aspect of the world where people live.

Despite the complexities and importance of planning for WSCs, most research focuses on the management side. For example, it focuses on technology evaluation, optimisation and performance simulation, often with an emphasis on biophysical factors (Fryd *et al.*, 2012; Lerer *et al.*, 2015). Literature on WSCs is often focused on highlighting the features of a WSC rather

than strategic planning for a WSC (Kumar *et al.*, 2023).

Kuller *et al.* (2017) warn that the result of ad-hoc, incremental and reactionary planning and implementation could be technologically optimised systems that do not reach their full water sensitive potential in practice. The authors offer three principles for successful planning: (1) Adopting a more holistic approach which considers all relevant technical, social, economic and environmental factors related to urban design, (2) Considering all relevant scales at which the problem is to be addressed, and (3) Engaging all relevant stakeholders in the planning process from an early stage, through effective communication and cooperation. The principles of integration, sustainability, resilience and liveability need to be incorporated strategically and early in the planning process for all systems claiming to be water sensitive. Planners and decision makers need to address the ‘*interplay between technical systems, socio-political contexts, professional praxes and biophysical realities*’ if the full benefits of WSC systems are to be realised (Fryd *et al.*, 2012).

2.5 Water Sensitive Cities in South Africa

WSUD and WSCs emerged in Australia and were formalised by an Australian research centre – the CRCWSC. Whilst the concepts have a degree of universality, some aspects, particularly related to the initial principles, are particular to Australia and Global North contexts more generally. This section presents a case study of WSCs in the Global South context of RSA. It describes how the concept was adapted and translated through various initiatives and publications.

The ‘South African Guidelines for Sustainable Drainage Systems’ were published in 2013 (Armitage *et al.*, 2013). They were followed by the ‘Framework and Guidelines for Water Sensitive Urban Design for South Africa’ in 2014 (Armitage *et al.*, 2014). Both guidelines were published through the South African Water Research Commission (WRC) and undertaken by the Urban Water Management Group, now the Future Water Institute, at UCT. This was followed by the WRC’s development of a WSUD CoP in 2014, which was also led by the Urban Water Management Group at UCT. WSUD was also established as one of the WRC’s five research platforms in 2015 (Figure 8).

The 2014 Framework and Guidelines for WSUD in RSA state ‘*Water sensitivity in RSA is defined as the management of the country’s urban water resources through the integration of the various disciplines of engineering, social and environmental sciences – whilst acknowledging that: RSA is water scarce; access to adequate potable water is a basic human right; the management of water should be based on a participatory approach; water should be recognised as an economic good; and water is a finite and vulnerable resource, essential to sustaining all life and supporting development and the environment at large*’. The document splits the WSUD term into three components to be considered in an integrated manner: (1) WSUD brings the concepts of ‘water sensitivity’ and ‘urban design’ together, (2) water sensitive urban planning (WSUP) deals with urban planning and governance aspects, and (3) water sensitive urban

management (WSUM) deals with the post construction management of water sensitive infrastructure (Armitage *et al.*, 2014).



Figure 8: Milestones in the evolution of WSUD and WSC in RSA (Carden & Fell, 2021)

The water sensitive narrative for RSA in the guidelines was ‘...mitigating water scarcity, improving water quality, thereby protecting ecosystems, through the development of water sensitive urban areas (for all) that are sustainable, resilient and adaptable to change, while simultaneously being a place where people want to live...’. The framework acknowledges that any WSC transition needs to consider both formal and informal areas, the latter of which are characterised by high densities and limited access to water, sanitation drainage and solid waste services.

After the transition to full democracy in 1994 in RSA, focus was placed on expanding water services provision to un-serviced communities, however this often came at the expense of infrastructure maintenance and environmental protection. This caused knock-on impacts such as poor water quality within and downstream of urban areas. Given these realities, the UWMTF was adapted by Armitage *et al.* (2014) for RSA to show a potential path to a WSC (Figure 9). RSA cities are characterised by both formal and informal areas that have hugely different levels of urban water services and will thus likely pass through different transition states on the path to a WSC.

The first few years after the 2014 framework was published were largely focused on WSUM. Both local government and industry-based professionals (mainly engineers and scientists) grappled with the operationalisation of the concept in their respective contexts. However, for a WSC to have the intended impact, planning has to play a crucial role. Relevant water sensitive principles need to be strategically included from the start (Fourie *et al.*, 2020b).

Planning water services with WSC objectives is complex in South African cities with limited budgets, siloed institutional arrangements and deteriorating water infrastructure. There is weak governance and planning capacity, and competition for land with dynamic patchworks of informal and backyarder households in-between the formal (fully serviced) developments. The country is rapidly urbanising, and its cities face multiple water management and planning issues alongside other social, political and economic factors.

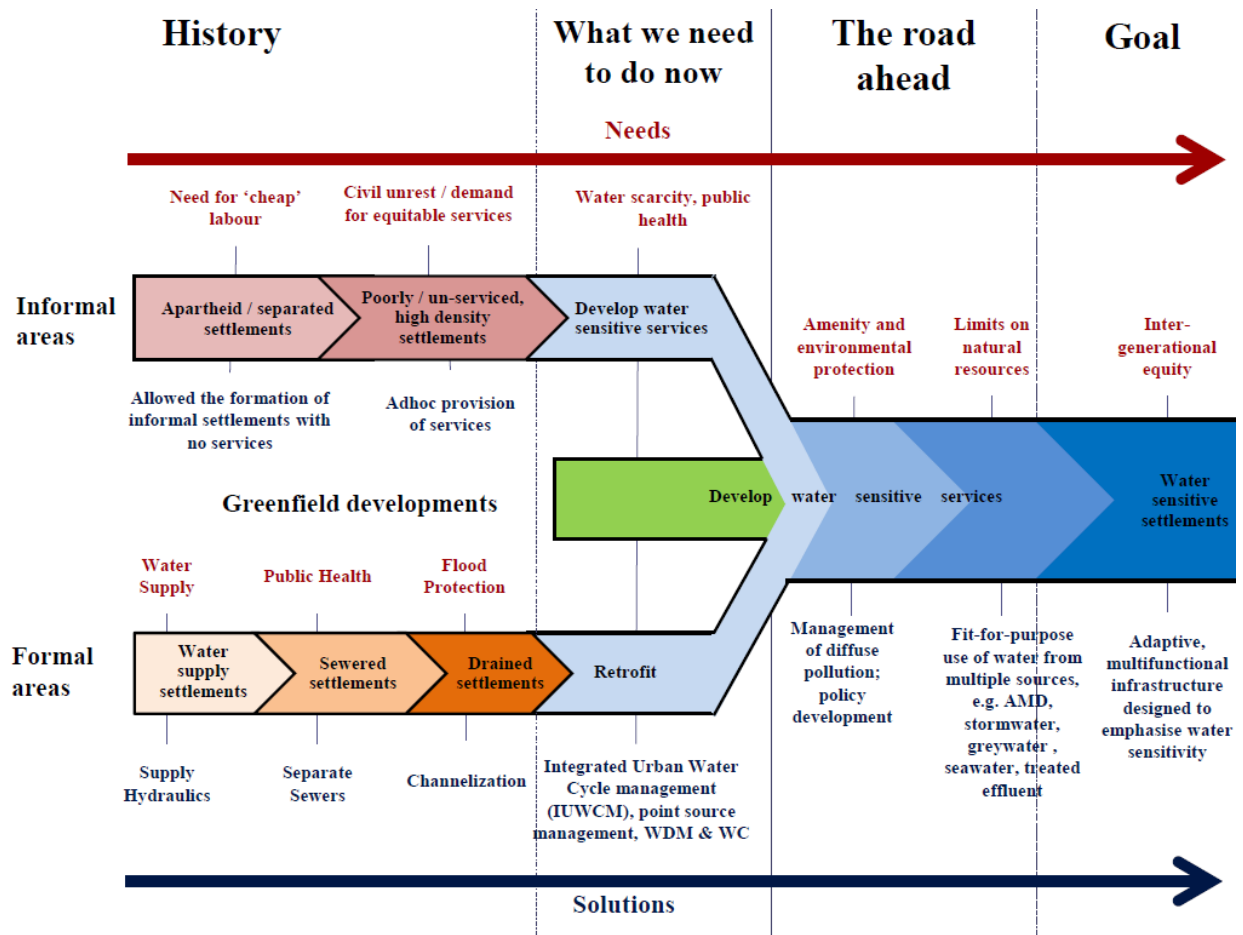


Figure 9: Framework for achieving a WSC in RSA (Fisher-Jeffes *et al.*, 2017b)

The 'Guideline on Compiling Water-Sensitive Spatial Plans' and 'Framework Towards Water-Sensitive Spatial Planning and Land Use Management' published in 2020 by the WRC go some way in integrating spatial planning and WSCs (Fourie *et al.*, 2020a, 2020b). These two documents indicated the importance of planning support for transitioning to WSCs at all scales from the metropolitan to the site level. Figure 10 shows the key elements that can be used to include and address water sensitivity in municipal planning documents. The biophysical aspects encompass the climate, hydrological and geological characteristics. Furthermore, they include areas of ecological significance (including critical biodiversity areas and ecological support

areas) and areas with groundwater resources of a high value. The water sensitive modelling assessment comprise the determination of areas of environmental conflict, potential areas that can be used to expand protected areas and surface water protection and conservation zones. Other elements include: groundwater protection, current and future water demand patterns, the potential for rainwater harvesting, and the delineation of blue-green corridors.

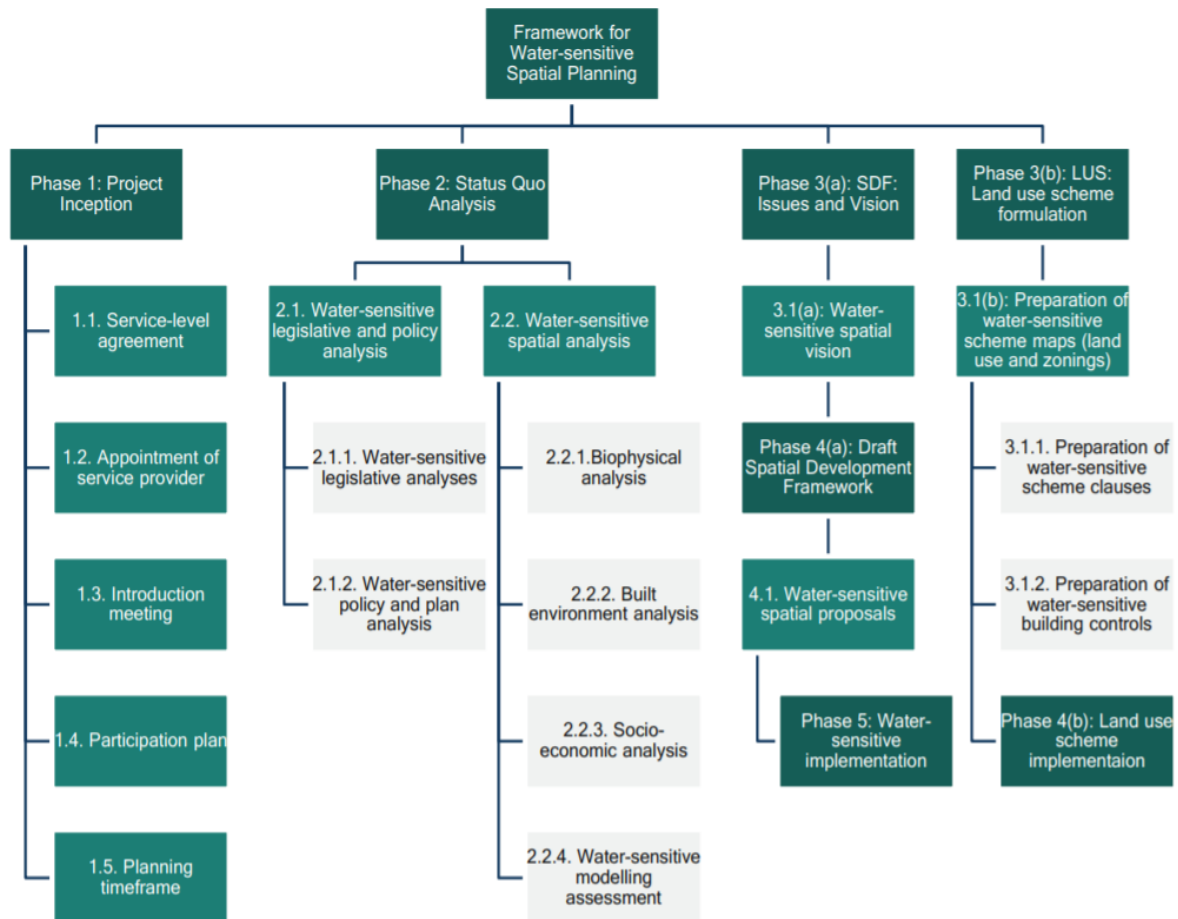


Figure 10: The framework for water sensitive spatial planning (Fourie *et al.*, 2020a)

2.6 Frameworks for planning Water Sensitive City systems

The social, ecological, economic, institutional and biophysical complexities of planning for WSC systems, including BGI, is supported in the literature by a range of frameworks, processes and tools. These have been organised by various authors: Lerer *et al.* (2015) mapped WSUD planning tools based on their functionality. Fryd *et al.* (2012) developed a framework to aid planners in considering the multidimensional and -disciplinary aspects of SuDS planning. Kuller *et al.* (2017) built on this framework to create a typology of WSUD Planning Support Systems (PSS) and framing. Meerow *et al.* (2016) proposed a conceptual schematic of the urban system with an

accompanying framework for considering resilience for whom, what, when, where, and why for GI planning.

Lerer *et al.* (2015) classified WSUD planning tools based on their main functionality, that is, by the questions they can assist in answering. Three main groups were identified: (1) ‘How Much’-tools, (2) ‘Where’-tools and (3) ‘Which’-tools. The authors further distinguished between the tools by their focus, either on biophysical elements (physical, chemical and biotic) or human aspects (historical, linguistic, social, economic, aesthetic, legal and moral). The ‘How Much Water, Where and Which’ tools provide quantitative answers related to hydraulic, hydrologic, water quality, liveability and economic aspects. Examples of these tools included SWMM, MIKE URBAN, MUSIC and MODFLOW. The ‘where can WSUDs be implemented’ tools are linked to site suitability and location and often use GIS. Most tools address the physical environment. A few tools considered biotic, social, aesthetic and legal aspects. The authors highlighted the limitations of commonly used hydraulic models, such as SWMM and MIKE URBAN, to address the multifunctionality of systems for a WSC. MCA tools were found to address more aspects than any others.

Fryd *et al.* (2012) presented a framework for SuDS planning consisting of three axes of time, space and human values. The framework had three thematic planes of biophysical processes (e.g., engineering), spatial strategies (e.g., urban design) and adaptive strategies (e.g., management), which reflected the three disciplinary domains of engineers, architects and management experts (Figure 11). The framework showed the interactions between the themes and disciplines over time. It showed the nature of SuDS planning as a converging process with iterative loops between the axes, thematic planes and actors. The human values axis – which was rooted in a continuum of ecocentric and technocentric worldviews/values – emphasised the role of economic, technological, legal and political elements influencing human choice. The framework emphasised the need for planning to incorporate multiple factors, benefits, scales and disciplines related to SuDS.

Kuller *et al.* (2017) built on the SuDS planning framework of Fryd *et al.* (2012) and developed a typology for WSUD PSS (Figure 12). The typology uses three thematic dimensions for the biophysical processes, spatial strategies and adaptive strategies. It characterises three approaches of PSS towards WSUD: ‘WSUD as part of the urban water cycle’, ‘WSUD as part of the urban form’ and ‘WSUD as part of water governance’. As with Lerer *et al.* (2015), Kuller *et al.* (2017) assert that biophysical processes supported by water balance models and hydrological/hydraulic models, have been the traditional focus of urban water management.

‘WSUD as part of the urban form’ considers WSUD planning as a location choice, within the dimensions of space and human decision making. Four categories of tools are identified as: planning simulation, technology selection, technology evaluation and spatial suitability evaluation. These tools are used during the conceptualisation and planning stages. They are typified by their ability to incorporate multiple social, ecological and biophysical factors and often use multi-criteria decision analysis (MCDA) techniques. MCDA techniques are favoured for WSUD planning as they can include different decision criteria, are easy to use, have flexibility

of scale, and can be provided with interactive and visual outputs. Kuller *et al.* (2019) produced a Geographic Information System multi-criteria decision analysis (GIS-MCDA) tool for spatial suitability assessment of green urban stormwater infrastructure in cities. An example of a technology evaluation tool is the Benefits Estimation Tool (BEST) which identifies, assesses and values a variety of benefits of BGI projects, including a monetary value (CIRIA, 2021; Ashley *et al.*, 2022).

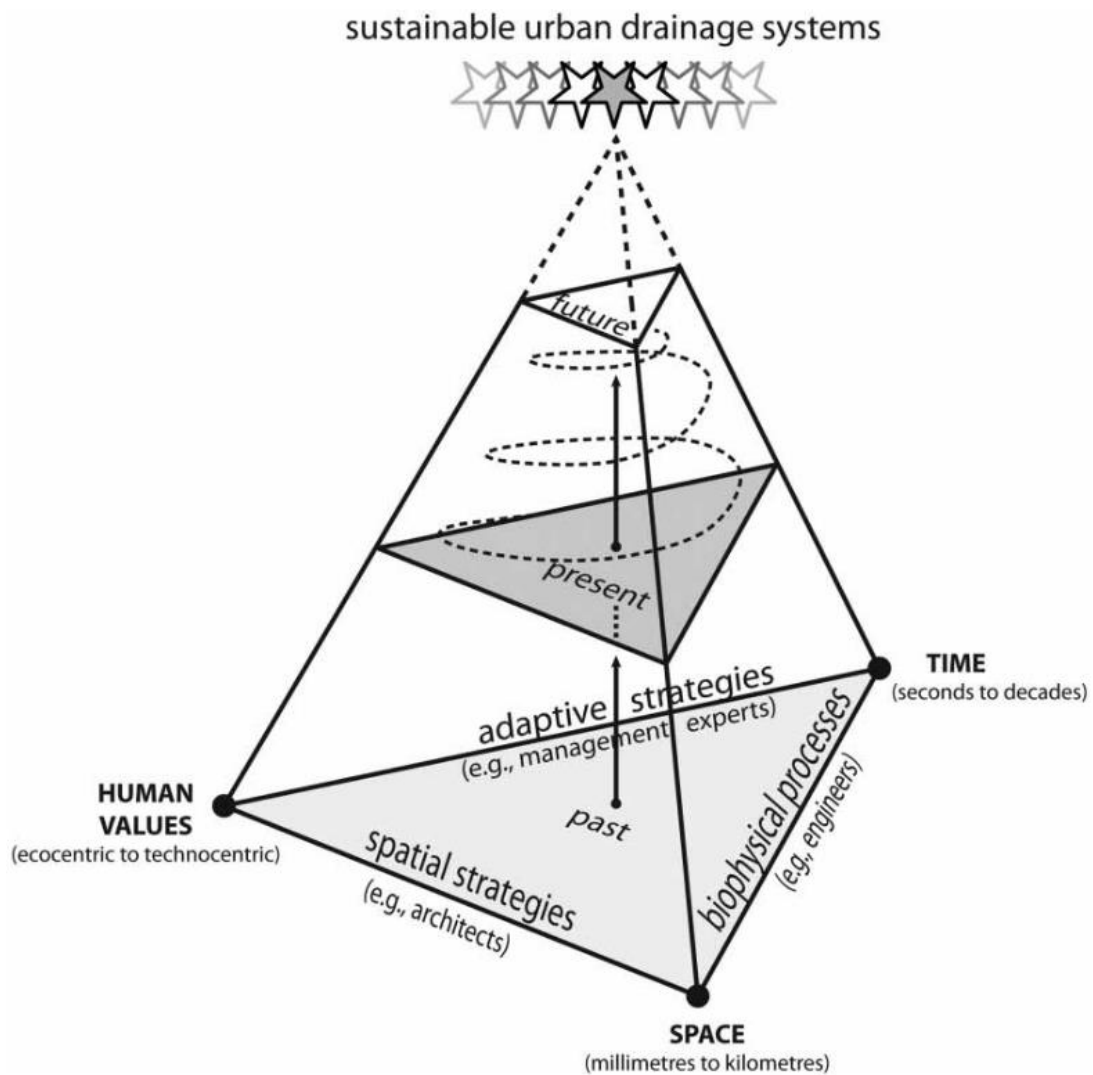


Figure 11: Framework for the planning and design of SuDS (Fryd *et al.*, 2012)

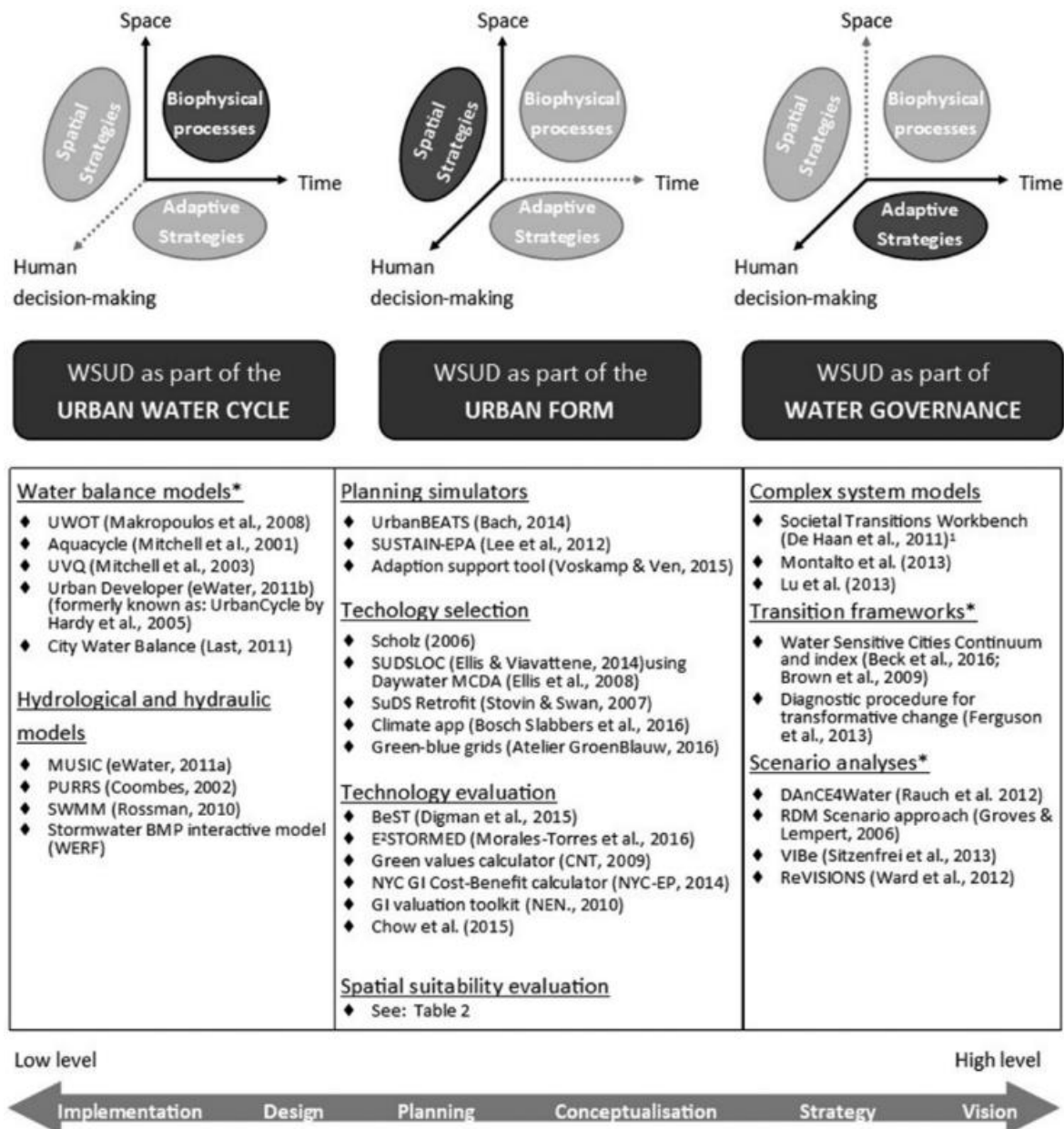


Figure 12: Typology of urban water PSS (Kuller et al., 2017)

Meerow *et al.* (2016) proposed a definition and associated conceptual schematic of the urban system in the context of urban resilience (Figure 13). Urban resilience fulfils the function of a boundary object in the system. The schematic highlights the flexibility of the resilience concept to be adapted to different disciplines and stakeholders and address different urban domains.

Meerow and Newell (2019) then built on this by proposing the use of five diagnostic questions: whom, what, when, where, and why, to be used when planning for and operationalising resilience (Table 2). The ‘five Ws of urban resilience’ framework emphasises the political nature and contested process of resilience planning. It involves multiple diverse stakeholders with differing value systems. It presents a list of questions to be considered in the

process of understanding and enacting urban resilience, and the associated trade-offs and dimensions. The authors applied it in the empirical context of expanding GI where it assisted in the identification of the maximum likely benefits, where they are needed, and the identification of priority areas with the use of a GIS-MCDA approach.

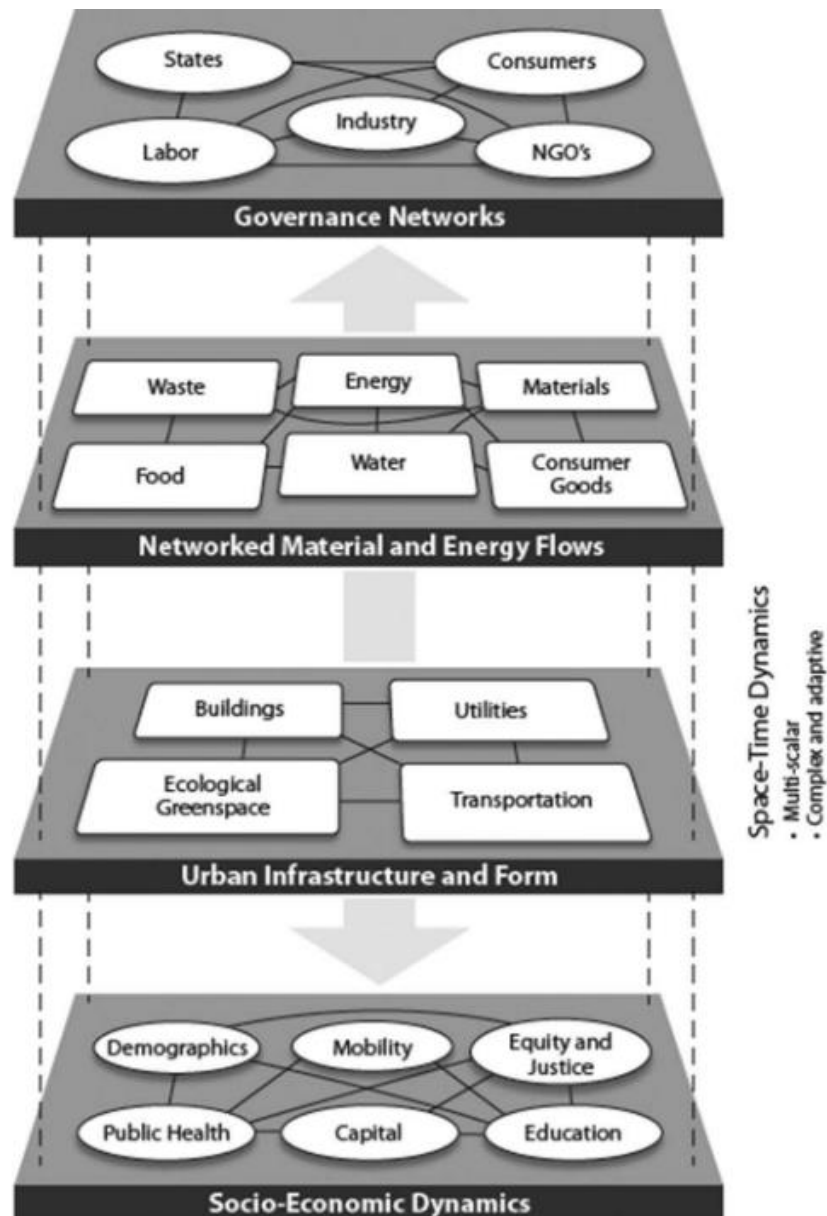


Figure 13: A conceptual schematic of the urban system (Meerow *et al.*, 2016)

The frameworks in this section highlight the need for planning tools that can incorporate multiple diverse factors and go beyond traditional biophysical considerations. They emphasise the need for an integrated and strategic approach that is sensitive to context when planning WSC systems – as can be provided by MCA.

Table 2: The five W's of urban resilience framework (Meerow *et al.*, 2016)

		Questions to consider
Who?	T	Who determines what is desirable for an urban system?
		Whose resilience is prioritised?
		Who is included (and excluded) from the urban system??
What?	R	What perturbations should the urban system be resilient to?
	A	What networks and sectors are included in the urban system?
	D	Is the focus on generic or specific resilience?
When?	E	Is the focus on rapid-onset disturbances or slow-onset changes?
	-	Is the focus on short-term resilience or long-term resilience?
	O	Is the focus on the resilience of present or future generations?
Where?	F	Where are the spatial boundaries of the urban system?
	F	Is the resilience of some areas prioritised over others?
	S	Does building resilience in some areas affect resilience elsewhere?
Why?		What is the goal of building urban resilience?
		What are the underlying motivations for building urban resilience?
		Is the focus on process or outcome?

2.7 Blue-Green Infrastructure planning

Multi-criteria approaches are often used for planning and evaluating BGI (Viavattene & Ellis, 2011; Bach, 2014; Lerer *et al.*, 2015; Di Matteo *et al.*, 2017; Kuller *et al.*, 2017). They are particularly suitable considering BGI's defining characteristic of providing multiple benefits, and the challenging urban contexts that need to be considered for implementation. MCA is flexible, able to incorporate multiple diverse criteria, sensitive to context, multidimensional, strategic and participatory (Dodgson *et al.*, 2009; Malczewski & Rinner, 2015).

The approach is particularly useful in incorporating intangible benefits that cannot be quantified in monetary terms, such as amenity, biodiversity and water quality control. MCA can be applied for different purposes and scales. It is relevant in different decision contexts including evaluating the multiple benefits of a potential or current BGI system, selecting an appropriate BGI system to implement, or undertaking suitability assessments on where to place BGI systems (Kuller *et al.*, 2019). In short, MCA is equipped to address the complexities of planning for a WSC using BGI as a strategy.

2.8 Multi-criteria analysis

MCA consists of various methods, techniques and procedures for structuring planning and

decision problems. It comprises methods for designing, evaluating and prioritising decision alternatives for planning (Dean, 2022). The process does not seek the ‘best’ solution to a problem but rather assists with developing a constructive and creative approach. Dodgson *et al.* (2009) explain that an MCA ‘*establishes preferences between options by reference to an explicit set of objectives that the decision making body has identified, and for which it has established measurable criteria to assess the extent to which the objectives have been achieved*’. In the literature MCA is also known by the names of multiple-criteria decision making, multiple-criteria decision analysis, multi-objective decision analysis, multiple-attribute decision making or multidimensional decision making.

The process of decision making in MCA typically follows the process of establishing objectives or goals, identifying options for achieving the objectives, selecting criteria to measure performance and compare the options, analysis of the options (including value scaling or scores and criteria weighting) and planning and making decisions. Malczewski & Rinner (2015) define three main elements in an MCA: decision maker(s), options or alternatives, and criteria. The authors further define three main steps: value scaling, criterion weighting and combination (decision) rule. MCA is an alternative to other analytical techniques for evaluating options; for example, cost effectiveness analysis and cost-benefit analysis are generally mono-criterion methods using monetary valuations (rather than multiple criteria) to compare options.

MCA should be considered as an umbrella term. It is a large and diverse field with many tools and techniques to formally incorporate multiple criteria. Dean (2022) describes a ‘methodological chaos’ that can occur with MCA due to the variety of approaches. This can often lead to either the use of highly elaborate and mathematically complex MCA approaches or simplistic and rough MCA applications. The authors propose a classification of MCA methods that distinguishes between formal and simplified methods (Figure 14). The formal methods are further split into continuous and discrete methods. Continuous methods pertain to problems with an infinite number of options while discrete methods are used where there are bounded and well-defined options. Within discrete methods, full aggregation methods include the Multi Attribute Utility Theory (MAUT) methods, for which value functions and weights are expressed between zero (worst utility) to one (best utility). It includes the related Simple Multi Attribute Rating Technique (SMART) and the Analytic Hierarchy Process (AHP) developed by Saaty (1980). The AHP uses pairwise comparisons and a one to nine preference scale for scores and weights. Partial aggregation methods include Preference Ranking Organisation Method for Enrichment Evaluation (PROMETHEE) and Elimination and Choice Translating Reality (ELECTRE) methods.

In contrast to formal methods which are often elaborate and complicated, simplified methods are widely used for practical reasons. In particular, simple additive weighting methods are popular and applied extensively. These methods use the weighted additive model, also referred to as weighted sum, weighted average, weighted overlay or weighted linear combination, used in MAUT, SMART and AHP applications. The weighted additive model calculates the overall performance of the options by summing together all the products of criteria with their

respective weights. It indicates to planners what the ‘best’ option is. The results are presented in a performance table or matrix where a row shows a specific criterion and a column shows the weight (in the top row), and the performance scores of a particular option(s) against that criterion (Dodgson *et al.*, 2009). The weighted additive model has been widely used in water-related planning studies (e.g., Kremer *et al.*, 2016; Meerow & Newell, 2017; Morgan & Fenner, 2019; Goodspeed *et al.*, 2021; van Oorschot *et al.*, 2021).

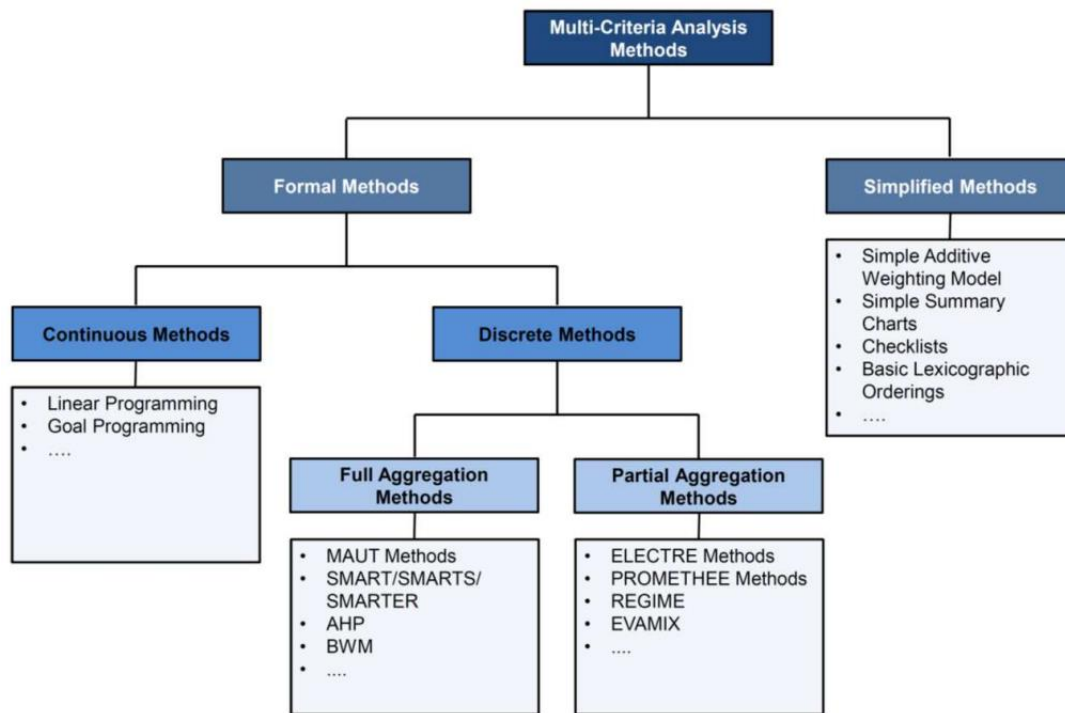


Figure 14: Classification of MCA methods (Dean, 2022)

MCA methods can be non-participatory or participatory. Non-participatory approaches are analyst led and usually technocratic in nature; they are suitable where there is certainty in the decision context. Participatory methods involve relevant stakeholders that represent different priorities contributing to either all or some of the key elements of an MCA – identifying objectives, criteria, options, weights and scores. Participatory MCA covers a broad range of different approaches for including stakeholders which each have their own advantages and disadvantages. Stakeholders can be defined as ‘*individuals or groups of individuals who have a vested interest in the problem under examination and who can influence or are influenced by the outcomes of the decision-making process*’ and can include experts relevant to the MCA focus (Dean, 2018). Integrating stakeholder perceptions and interests is considered as invaluable for general planning for complex issues that impact society at large, such as BGI (Venter *et al.*, 2021; Dean, 2022).

Many different people are impacted by the related decisions in the case of city-wide

planning for infrastructure such as BGI. It is thus preferable to get a range of perspectives and a balance of value systems for democratic decision making. Participatory MCA is thought to strengthen the transparency, quality and legitimacy of decision making informed by MCA (Dean, 2018). Ideally all stakeholders impacted by the planning issue should be included, however practical issues usually limit participants, with a review by Dean (2018) indicating that rarely more than 30 stakeholders are involved.

There are two major approaches to planning and decision making according to Keeney (1992): alternative-focused approaches and value-focused approaches. Alternative-focused approaches begin with the development of alternatives (also referred to as options) and then proceed with defining values, objectives and criteria for evaluation. Value-focused approaches start with an articulation of values (also referred to as principles, goals or aims) as the fundamental component of planning – putting focus first on what is desired rather than on the set of alternatives. Once values are defined, the options are identified as a means to achieve the values. The criteria are then selected to reflect the values or objectives to be achieved. Alternative-focused thinking risks the objectives and criteria being chosen by the defining characteristics of the predefined options.

Keeney (1996) asserts that values are the most important element and thus our decision making and planning processes should be driven by values. The author argues that the standard alternative-focused approach to problem solving is backwards, and value-focused thinking should thus be adopted for proactive rather than reactive approaches. Values improve planning by articulating upfront what is important. They can be used inform the alternatives, which are then evaluated. In Figure 15, Keeney (1994) illustrates the fundamental role of ‘thinking about values’ in planning and decision making.



Figure 15: The advantages of value-focused approaches (Keeney, 1994)

2.9 Key steps of a multi-criteria analysis: Evaluating Blue-Green Infrastructure

MCA has a set of typical main steps. These can vary in nature and order depending on the method used and the decision problem. Given the variety of MCA methods, and their associated steps, what formally defines a method is explained by Dean (2018) as the ‘*set of rules establishing the nature of objectives, criteria, options, scores and weights and the way in which these elements are ultimately aggregated together*’. In a value-focused approach, the steps usually are: (1) Primary problem analysis/problem recognition and structuring, (2) Identification of objectives and associated criteria against which to test options, (3) Development of the options or alternatives to be assessed, (4) Scoring to assess the performance of each option against the criteria, (5) Weighting of criteria, and (6) Combination of scores and weights (Dodgson *et al.*, 2009; Dean, 2022). The steps of identifying objectives, criteria and options, and weighting can often be an iterative process with feedback loops (Corner *et al.*, 2001). The general steps of a typical MCA, which relies on the weighted additive model, are described in this section and explained with examples from WSC, BGI and GI planning literature. The weighted additive model is classified as a simple MCA method that is widely used for its flexible and adaptable nature (Figure 14).

2.9.1 Primary problem analysis

The primary problem analysis or the problem formulation phase involves identification of the problems and relevant issues as well as the scope of the analysis. At this stage, the values and objectives of the process and the boundaries of the system are defined. The level of participation in terms of number and types of stakeholders is considered and participatory techniques are examined. The choice and articulation of scale plays an important role in this step, with the selection of site to neighbourhood to city to regional scale influencing various subsequent steps of the MCA (Langemeyer *et al.*, 2016).

Table 3 shows different typologies of planning and decision making processes which MCA can assist with when defining the scope of the analysis. These can either ‘close down’ or ‘open up’ the MCA (Keeney, 1992; Roy, 1996). An underlying approach of ‘closing down’ the analysis often provides a response illuminating the ideal way forward. ‘Opening up’ the analysis assists with providing an understanding of the multiple dimensions, stakeholders and information connected to the problem.

In developing a Green Infrastructure Spatial Planning model, Meerow & Newell (2017) articulate the planning problem nature and scope as a city scale and stakeholder-informed approach to identify ecosystem service trade-offs, synergies and hotspots for siting GI for urban resilience. Fluhner *et al.* (2021) defines the problem context as planning for the implementation of retrofitted and multifunctional urban GI in urban Global South settings with reference to a neighbourhood scale case study in the metropolitan region of Costa Rica. Contextual limitations included the state of infrastructure development and informal settlements.

Table 3: The scope of MCA problems (adapted from Dean (2022))

Type of problem	Description of scope	Underlying approach to the analysis
Ranking problem	Comparing different options and place them in some form of preference ordering.	Closing down
Choice problem	Choosing the most suitable alternative from a set of feasible options.	Closing down
Sorting problem	Sorting the options into classes such as ‘acceptable for further analysis’, ‘possibly acceptable but in need of more information’ and ‘unacceptable’.	Opening up/closing down
Description problem	Producing a formal and systematic examination of the key features of one or more options and their consequences, rather than on simply trying to rank them.	Opening up
Design problem	Generating entirely new options.	Opening up

2.9.2 Identification of objectives and criteria

The objectives and associated criteria against which to test options are identified after the problem formulation phase. Objectives are high level aims or goals that qualitatively define what is important. They are statements of something being aspired to, and are often categorised as social, environmental, physical or institutional. For BGI planning, objectives often include goals of resilience, sustainability, liveability and/or water sensitivity. The ecosystem services categories of provisioning, supporting, regulating and cultural are also often used to organise the objectives. Objectives are informed by values and are a means to make values explicit.

Objectives can be distinguished into fundamental objectives and means objectives, particularly for value-focused approaches. Fundamental objectives refer to an essential reason related to the decision context. Means objectives are way to achieve the fundamental objectives. They can assist with an approach to analysing problems and for creating alternatives, but the fundamental objectives perform the essential work of guiding planning and evaluating the alternatives. Objectives can also be classified into a single high-level objective with sub-objectives (Dodgson *et al.*, 2009). The process of developing objectives often involves engagement with relevant stakeholders. Table 4 presents techniques for developing objectives.

Meerow & Newell (2017) were guided by the value of urban resilience. The fundamental objectives were: managing stormwater, reducing social vulnerability, increasing access to green space, reducing the UHI effect, improving air quality and increasing landscape connectivity. The means objective was expanding GI. In another study on green roofs to reduce heat stress, Sharma (2018) specified three fundamental objectives: (1) reduce urban temperatures, (2) reduce exposure of vulnerable populations to heat impacts, and (3) reduce electricity consumption. Other examples of fundamental objectives used in GI studies include ecosystem restoration through green roofs (Venter *et al.*, 2021) and the protection of valuable areas and restoration of degraded

areas for a local park (Zucca *et al.*, 2008).

Table 4: Techniques for developing MCA objectives (adapted from Keeney (1994))

Techniques	Questions to consider
A wish list	What is wanted? What is valued? What should be wanted?
Alternatives	What is a perfect alternative, a terrible alternative, some reasonable alternative to achieve the objectives? What is good or bad about each option?
Problems and shortcomings	What is wrong or right? What needs fixing?
Consequences	What has occurred that was good or bad? What might occur that is important?
Goals and constraints	What are the aspirations? What limitations are there?
Different perspectives	What would be of concern given different perspectives? At some time in the future, what would be of concern?
Strategic objectives	What are the ultimate objectives? What are values that are absolutely fundamental?
Generic objectives	What are the objectives? What environmental, social, economic, or governance objectives are important?
Structuring objectives	Follow means-ends relationships: why is that objective important, how can it be achieved? Use specification: what is meant by this objective?
Quantifying objectives	How would achievement of this objective be measured? Why is objective A three times as important as objective B?

The initial structuring (identifying objectives and options) and the criteria of the decision problem are among the most important aspects of an MCA (Hajkowicz & Higgins, 2008). Criteria provide a way to measure the extent that options meet the objectives through measurable indicators of performance (Hiremath *et al.*, 2013). A criterion refers to the desired state of the system under consideration (objective). They must be measurable to allow for the assessment of how well a particular option is expected to perform in relation to the criterion, and the level of achievement of the objective. Criteria reflect the many ways that options create value, showing benefits that can be provided. In the related context of indicators, Meadows (1998) notes that '*indicators arise from values (we measure what we care about), and they create values (we care about what we measure)*'. As simplifications of reality, criteria need to be able to reflect aspects of reality in the context(s) in question. Criteria are typically organised or clustered under themes in the objectives. They can be quantitative or qualitative, and spatially explicit or implicit. Criteria are means to an end as well as a simplified version of the end itself. The process of criteria development is as important as the criteria selected. Indeed, problem framing and criteria development can be considered part of the results of (socio-environmental) modelling (Voinov *et al.*, 2014). A set of criteria should have the properties of exhaustiveness, manageability, understandability, measurability and non-redundancy. Table 5 presents a selection of studies that use a multi-criteria approach, and the respective criteria they employed. The scale of the study impacts the type and level of detail of the criteria.

Table 5a: A selection of studies using multi-criteria approaches for BGI and SuDS planning and decision making

Title	Purpose	Criteria	Reference
Prioritizing Suitable Locations for Green Stormwater Infrastructure Based on Social Factors in Philadelphia	Siting green stormwater infrastructure through the development of a model for the balancing of social factors with the constraints of the built environment in prioritising the implementation of green stormwater infrastructure within Philadelphia, America.	Ranked proximity to the built and social environments of Stormwater Inlets, Transit Stops, Neighbourhood Advisory Committees, Schools, Universities and recreation centres.	Christman <i>et al.</i> (2018)
Multi-criteria Approach for Selection of Green and Grey Infrastructure to Reduce Flood Risk and Increase CO-benefits	Method for selection of structural measures for flood risk reduction, with the main objective to support decision making processes by allowing the selection of adequate measures in accordance to local conditions and preferences.	1. Flood reduction reliability – high, medium or low return period. 2. Cost reduction – suitability (public space availability, type of roads, land use and population density, volume reduction for Waste Water Treatment Works (WWTWs), sewer system type), land take, investment and maintenance cost. 3. Co-Benefits – water quality, environmental (ecology/habitat creation, groundwater recharge/water re-use, air quality), liveability (aesthetics/amenity, urban heat reduction, community acceptability), economic (production capacity, energy saving), socio-cultural (educational activities, sense of community generation, recreational uses).	Alves <i>et al.</i> (2018)
Multifunctional retention pond for stormwater management: A decision-support model using Analytical Network Process and Global Sensitivity Analysis	Develop a decision support tool for quantifying and evaluating the stormwater management performance of the multi functional retention ponds in urban areas.	1. Geotechnical functions – soils, infiltration rate, runoff quality treatment, drawdown time, backfill material, overflow route, seepage control, groundwater mound. 2. Water quality and treatment – soil retention, spillways, soil and groundwater aquifers, surface waters control, pollutant filtration system. 3. Structural and physical landscaping functions – observation well, outlets, slope control, pedestrian trails, facilities for pollutant and flow-rate control, vegetation, landscape habitat retention.	Keyvanfar <i>et al.</i> (2021)
A Planning Support Tool for Layout Integral Optimization of Urban Blue-Green Infrastructure	Develop a comprehensive solution for the integral optimisation of layout of BGI in the built environment.	Runoff intensity of sub-catchment area, Patch area and Euclidean nearest neighbour, Value above the mean Land surface temperatures, Density of urban residents, Plot area of public land and floor area ratio of public land, Floor area of representative buildings.	Zhou & Wu (2020)

Table 5b: A selection of studies using multi-criteria approaches for BGI and SuDS planning and decision making

Title	Purpose	Criteria	Reference
A planning-support tool for spatial suitability assessment of green urban stormwater infrastructure	Develop a WSUD PSS that automates user(s)-driven spatial suitability assessment for the planning of green stormwater control systems in urban environments.	Opportunities (Biophysical, Socio-economic, Planning & governance) – Slope, Roof areas, Environmental awareness, Sense of community, Utility infrastructure, Cultural Heritage, Land ownership. Needs (Provisioning, Regulating, Cultural) – Proximity to water demand, Heat vulnerability, Connected impervious area, Floods Visibility.	Kuller <i>et al.</i> (2019)
Spatial evaluation of the multiple benefits of sustainable drainage systems	Development of an alternative way of evaluating and comparing benefits of SuDS/GI, allowing spatial distribution and local context and circumstances.	Access to green space, pollutant trapping, carbon dioxide sequestration, flood damage avoided, habitat size and noise pollution attenuation.	Morgan & Fenner (2019)
Benefits Estimation Tool (B _{EST})	Valuing the benefits of BGI corresponding to the ecosystem services framework, including options to quantify and monetise some benefits.	19 Benefit categories – Air quality, Amenity, Asset performance, Biodiversity and ecology, Building temperature, Carbon sequestration and reduction, Crime, Economic growth, Education, Enabling environment, Flooding, Health, Noise, Recreation, Tourism, Traffic calming, Water quality and Water quantity.	Horton <i>et al.</i> (2019)
A GIS based decision support system for the implementation of Stormwater Best Management Practices	Development and application of a GIS decision support tool which facilitates the integration of data from a variety of sources to investigate the potential benefits of BMPs.	Technical – flood control, pollution control, adaptability to urban growth; Environmental – receiving water volume impact, receiving water quality impact, receiving water ecological impact; Operation and maintenance – maintenance and servicing requirements, system reliability and durability; Social and urban community benefits – public health and safety risks, sustainable development, public information and awareness, amenity, aesthetics; Economics – life cycle cost, long term affordability; Legal and urban planning – adoption status, building development issues and stormwater regulation.	Viavattene <i>et al.</i> (2008)
Planning for multifunctional urban green infrastructures: Promises and challenges	Development of a method that informs spatial priority areas towards GI planning by taking into account the assessment of different functions.	Local temperature regulation by green areas and population proximity to public green spaces.	Madureira & Andresen (2014)

Table 5c: A selection of studies using multi-criteria approaches for BGI and SuDS planning and decision making

Title	Purpose	Criteria	Reference
Spatial planning for multifunctional green infrastructure: growing resilience in Detroit	Development of the Green Infrastructure Spatial Planning model – a spatial planning approach to identify trade-offs and synergies associated with ecosystem services provided by GI, and to identify priority areas where GI can be strategically placed to leverage co-benefits.	Stormwater management, social vulnerability, access to green space, air quality, UHI, and landscape connectivity.	Meerow & Newell (2017)
Assessing urban ecosystem services in support of spatial planning in the Hague, the Netherlands	Development of a spatially explicit model to inform urban planners on priority areas for multifunctional GI development. The model involves a novel weighting scheme based upon the local capacity of GI to mitigate problems, with the application of the model to the city of The Hague, Netherlands.	Air pollution (Mitigation of PM10 concentrations), the UHI effect (land surface temperature) and storm water flooding (stormwater retention).	van Oorschot <i>et al.</i> (2021)
Assessing the potential of strategic green roof implementation for green infrastructure: Insights from Sumida ward, Tokyo	Spatially identifies areas where roofs have the potential to provide different types of benefits associated with urban green spaces if they are retrofitted with green roofs.	UHI effect mitigation, air pollution mitigation, and benefits to subjective wellbeing and biodiversity.	Aleksejeva <i>et al.</i> (2022)
Interactive spatial planning of urban green infrastructure – Retrofitting green roofs where ecosystem services are most needed in Oslo	Demonstrates the implementation of spatial MCDA to prioritise green roof locations at city scale with building resolution.	Temperature regulation, stormwater runoff mitigation, habitat for biodiversity, aesthetic value, and noise reduction.	Venter <i>et al.</i> (2021)

2.9.3 Option generation

The generation of options to be assessed can either come before or after the identification of objectives and criteria. In value-focused approaches, the generation of options comes after the objectives and criteria so as not to narrow the scope too early (Section 2.8) (Keeney, 1994). Options contribute to the achievement of objectives. They can include policy or planning or management alternatives, a choice of transport routes, geographical locations, land use alternatives, park features, a selection of projects to improve water quality or choices related to the expansion of BGI (Dodgson *et al.*, 2009; Langemeyer *et al.*, 2016).

For BGI planning, options often include: (1) evaluating the multiple benefits of current or potential BGI type(s) in general or for a certain context (BGI evaluation), (2) selecting BGI types or technologies on their ability to provide required functions or benefits in a context (BGI selection), or (3) assessing the spatial suitability or prioritisation of locations for new BGI to be introduced based on various benefits – usually through the spatially explicit method of GIS-MCDA (spatial suitability evaluation) (Malczewski & Rinner, 2015; Kuller *et al.*, 2017). These types of evaluations provide insight into priority areas or hotspots or BGI types where there is potential for benefit provision. For example, Venter *et al.* (2021) developed a method to prioritise sites to retrofit existing roofs to green roofs in locations where ecosystem services are needed most in Oslo, Norway. The study was at city scale with five ecosystem service benefits. Using a GIS-MCDA, Kuller *et al.* (2019), developed a planning support tool for spatial suitability assessment of green urban stormwater infrastructure. The tool maps suitability of locations for the introduction of WSUD assets across urban areas. Aleksejeva *et al.* (2022) catalogued roof space for green roof implementation in Sumida, Tokyo, Japan. The authors evaluated the potential of each roof patch to offer four types of benefits if retrofitted with a green roof: UHI effect mitigation, air pollution mitigation, and benefits to subjective wellbeing and biodiversity.

2.9.4 Performance scoring

Once the objectives, criteria and options have been selected, the next step is performance scoring. This involves scoring the performance of the options against the different criteria using a performance scale, also referred to as a value scale (Malczewski & Rinner, 2015). To make the performances comparable, and to evaluate and rank the options, the values need to be put onto a common scale. Performance scoring is the mathematical representation of human judgement and knowledge in the form of value functions (Keeney, 1992). Dean (2022) notes that performance scores represent pure numbers with no units and there is some unavoidable subjectivity in judging the impacts of the options. There are different types of performance scoring techniques including the proportional scoring approach, direct rating approach, pairwise comparison approach derived from the AHP method and a value function approach (Dean, 2022). The step of performance scoring is considered as more neutral and less contentious than other MCA steps such as weighting.

The proportional scoring approach is popular type of performance scoring. It is used for

quantitative based criteria where there are multiple options. The approach involves selecting an interval scale to measure the performance of the options against the criteria. A zero (worst performance) to one (best performance) scale is typically used. The option with the worst performance is then assigned the lowest score on the scale (zero), with the highest score of one assigned to the best performance of an option. The remaining options are then assigned intermediate scores relative or proportional to the zero and one scores and are typically represented by a linear (e.g., Meerow & Newell (2017)) or piecewise linear form (e.g., Kuller *et al.* (2019)).

For performance scoring, there is a distinction between local and global scales. Local scales are defined by the options under consideration. Global scales are defined by a wider set of possibilities often related to the ideal best and worst performance (Malczewski & Rinner, 2015). For example, Morgan & Fenner (2019) created a novel benefit curve based on the absolute best and worst achievable scores that do not change based on context for six benefits, that is, a global scale was used. The six benefits included access to green space, pollutant trapping, carbon dioxide sequestration, flood damage avoided, habitat size and noise pollution attenuation. For a proportional scoring approach, relatively worse performance on some criteria can be compensated by good scores on other criteria.

2.9.5 Criterion weighting

Criterion weighting is the next step after performance scoring. It involves the assigning of relative values, in the form of coefficients, to criteria to indicate their relative importance to each other. Objectives or criteria that are considered relatively more important receive a higher weight to reflect this (Malczewski & Rinner, 2015). The weighting step is both a critical and controversial one given the value judgements needed and the impacts on the rankings of the options (Dean, 2022). Participatory processes to obtain stakeholder weights are considered important and often necessary when planning BGI. Stakeholder derived weightings are often aggregated, with the mean weighting calculated (Meerow, 2019).

There are multiple weighting methods, and they can be classified into compensatory and non-compensatory techniques. Compensatory techniques provide full compensation between criteria. Non-compensatory techniques are used for establishing weights as importance coefficients (Dean, 2022). Common weighting methods include: ranking, point allocation, pairwise comparison (based on AHP), direct rating and ratio. In the ranking weighting method, criteria are ranked from most to least important. Three common approaches of rank sum, rank exponent and rank reciprocal may then be used to obtain the normalised weights. The point allocation weighting method is a simple one to use. It involves allocating a fixed number of points (often 100 points) to each criterion to reflect relative importance (ODU, 2019). However, the more criteria there are, the more challenging the point allocation method becomes. The pairwise comparison weighting method entails comparing criteria in pairs on a scale from one (two criteria with the same importance) to nine (one criteria is absolutely more important than the other one).

Once this has been completed, the geometric mean or the normalised principal eigenvector of the pairwise comparison matrices are calculated to obtain the weights (Dean, 2022).

2.9.6 Combination of scores and weights

Once the scores and weights have been assigned, they are combined and the overall performance of the options is calculated with Equation 1, for the weighted additive model.

$$S_i = w_1s_{i1} + w_2s_{i2} + \dots + w_ns_{in} = \sum_{j=1}^n w_j s_{ij} \quad (1)$$

where the preference score for option i on criterion j is represented by s_{ij} and the weight for each criterion by w_j , with n criteria the overall score for each option is S_i .

The MCA results are usually presented in performance tables, graphs or charts, and the overall performance score of the options may be used to produce a ranking of potential or prioritisation of different options. The results are often used to identify hotspots for BGI and GI planning and implementation. Maps are often used to visualise the results with colour coding to indicate high priority or potential. For GIS-MCDA methods, suitability maps are the outputs. Once the results have been obtained, they are used to inform planning and decision making processes.

The MCA results are often complemented by synergies and trade-offs, which are calculated between criterion scores, in research using MCA for planning BGI and GI, as well as in the ecosystem services literature. A negative correlation is used to represent a trade-off and a positive correlation to indicate a synergy between benefits (Bennett *et al.*, 2009; Raudsepp-Hearne *et al.*, 2010; Turner *et al.*, 2014; Meerow & Newell, 2017; Venter *et al.*, 2021).

The weighted additive model was used by Meerow & Newell (2017) for GI planning in Detroit, USA. The study used the weighting methods of ranking and pair-wise comparisons, along with an equal weighting, with the results mapped to show prioritisation for GI siting (Figure 16). The study also assessed synergy and trade-off patterns using Pearson bivariate correlations between the criterion scores (Figure 17). The weighted additive model was similarly used in the Blue-Green Cities – Multiple Benefit Toolbox in a weighted or unweighted way (Blue-Green Cities, 2017; Morgan & Fenner, 2019). Venter *et al.* (2021) used the weighted additive model to produce prioritisation layers for retrofitting existing roofs with green roofs in Oslo, Norway. The authors also calculated Pearson correlation coefficients to indicate trade-offs and synergies for the spatial prioritisation scores for roofs in Oslo (Figure 18). Aleksejeva *et al.* (2022), mapped the aggregated benefit score potential of green roof patches for assessing the potential of strategic green roof implementation for GI in Sumida ward, Tokyo, (Figure 19).

2.9.7 Benefits of a multi-criteria analysis

MCA has many benefits and advantages over informal judgement that is not accompanied by a structured and logical analysis (Dodgson *et al.*, 2009) including:

- it is open and explicit,
- it is comprehensive, flexible and able to incorporate a range of information, objectives and criteria that are both qualitative and quantitative in nature,
- the objectives and criteria are open to change and analysis upon interrogation,
- performance scores, weighting techniques, combination rules and the input data are explicit, use established techniques and can be cross-referenced to best practice sources and use expert input,
- it facilitates communication as the outputs can be made visual, and
- the techniques provide an audit trail.

However, Dean (2022) warns that MCA does not always result in better and more comprehensive decision making and planning. The author highlights gaps in theory and practice related to prohibitively complicated mathematical techniques, such as some of the formal MCA methods described in Section 2.8, and idealistic notions of participatory methods. The author lists some limitations as possible inconsistencies and lack of clarity: the disregard of economic efficiency consideration, lack of consideration of the temporal dimension, arbitrariness, the problematic determination of weights and uncertainties.

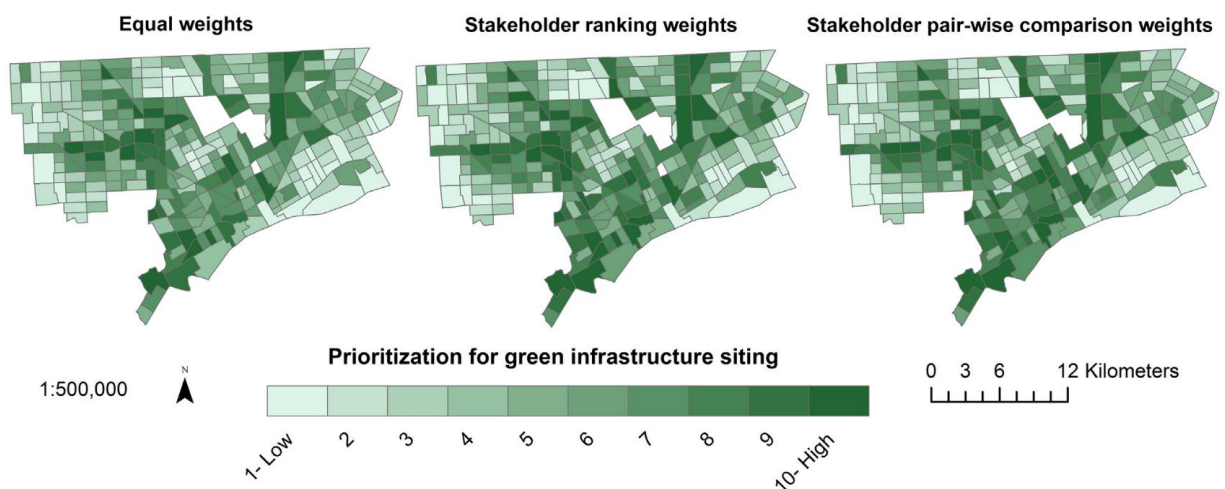


Figure 16: Results of the Green Infrastructure Spatial Planning model
(Meerow & Newell, 2017)

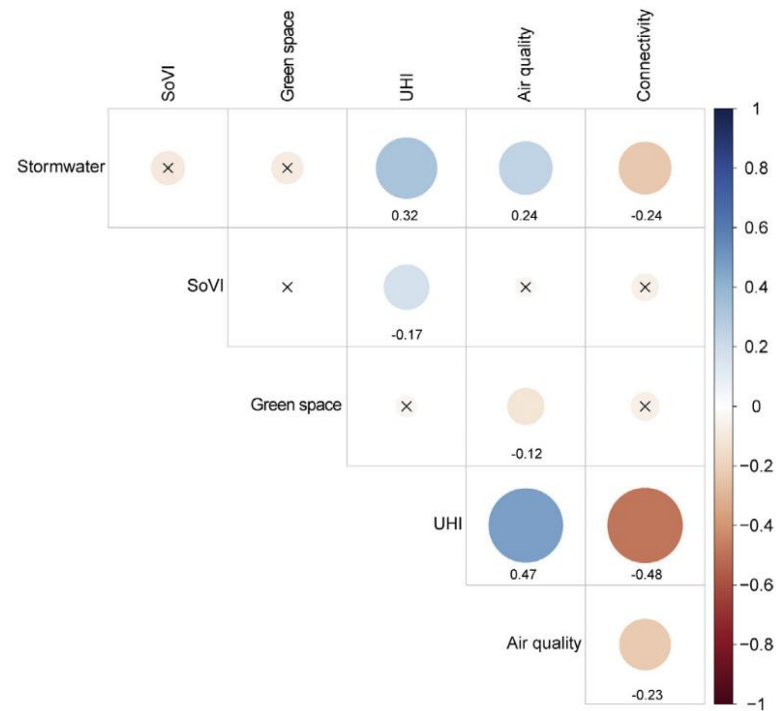


Figure 17: Synergy and trade-off patterns of the Green Infrastructure Spatial Planning model (Meerow & Newell, 2017)

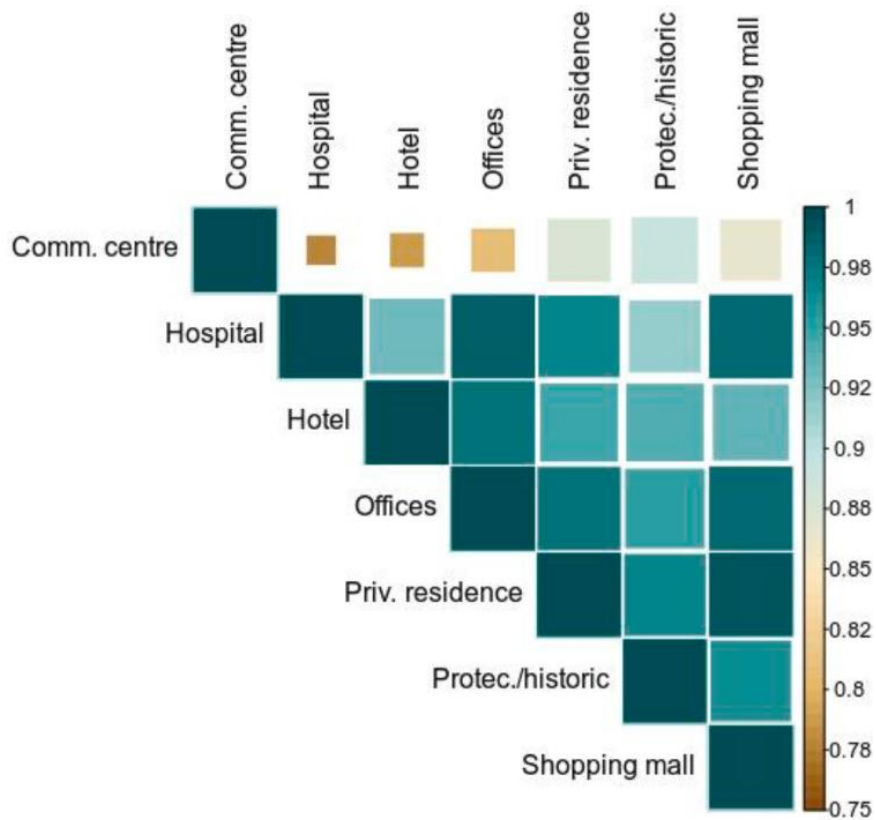


Figure 18: The correlation matrix for green roofs in Oslo, Norway (Venter *et al.*, 2021)

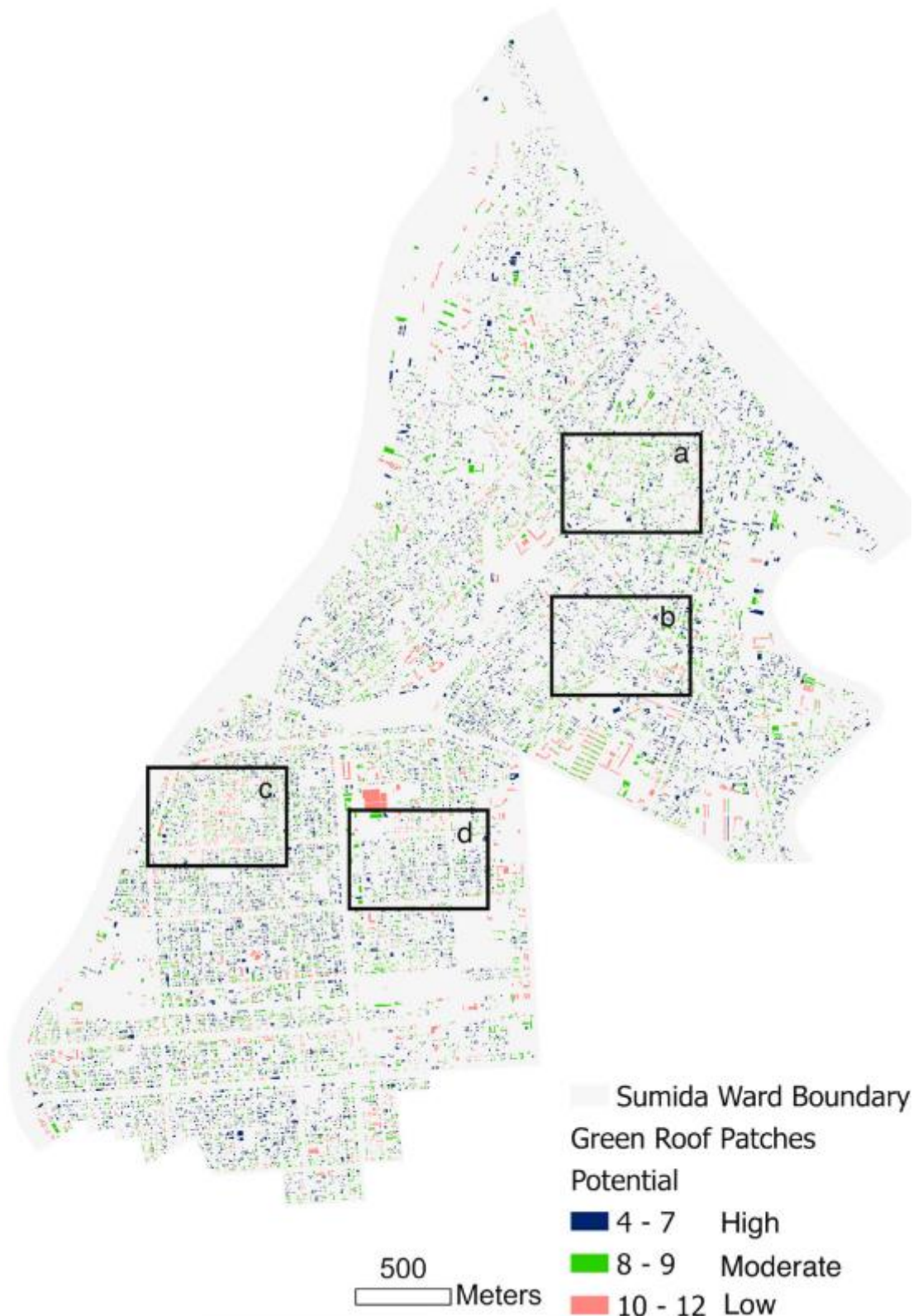


Figure 19: Aggregated benefit score potential of green roof patches in the Sumida ward
(Aleksejeva *et al.*, 2022)

2.10 Summary

As cities urbanise and grapple with climate change, land use change and resource challenges, there is an increasing shift towards a new water planning and management paradigm rooted in water sensitivity. The concept of a WSC forms a framework for a renewed approach. It offers a set of principles that underpin resilient, sustainable and liveable cities. BGI is an important component of a WSC. It can provide multiple benefits such as water re-use, enhanced biodiversity and improved amenity and liveability.

Planning for a WSC with multifunctional measures is complex and requires the inclusion of multiple disciplines and strategic approaches. The urban Global South context presents particular challenges. These are related to rapid urbanisation, degrees of informality and weak institutional capacity, with the concept of leapfrogging to a WSC presenting limitations. The case study of adapting and translating the WSC concept for the SA context highlights some contextual complexities.

The complexities of planning for WSC systems can be informed through various frameworks that emphasise MCA methods. MCA is commonly used for evaluating BGI as it can incorporate multiple diverse benefits through objectives and criteria. It is flexible, sensitive to context, such as challenging Global South contexts, strategic and participatory. MCA is a large and diverse field with multiple methods. The weighted additive model is a commonly used MCA method for BGI planning. It is best supported using value-focused approaches, which focus on values as the fundamental component of planning, rather than alternatives or options.

The MCA process of establishing objectives and criteria, identifying options, performance scoring, weighting, and combining the scores and weights, was detailed in this chapter. The steps were explained with BGI planning examples. This MCA process was used as the basis for the method, and for developing the MCA in the following chapter.

3. Research method

3.1 Introduction

The aim of this research was to develop an MCA methodology to evaluate the potential for existing BI to provide multiple benefits as BGI. This was done through the case study of existing stormwater ponds in Cape Town, RSA as part of its commitment to become a WSC. The literature review in Chapter 2 established that evaluating the potential for the provision of multiple BGI benefits can be successfully undertaken using MCA, which has been widely used for this purpose (Lerer *et al.*, 2015; Di Matteo *et al.*, 2017; Kuller *et al.*, 2017; Meerow & Newell, 2017). It is flexible, able to incorporate multiple diverse criteria, sensitive to context, multidimensional, strategic and participatory (Dodgson *et al.*, 2009; Malczewski & Rinner, 2015) (Section 2.8).

It is particularly suitable for BGI as multiple diverse benefits can be incorporated through the selection of objectives and criteria in a strategic manner (Section 2.9). It is sensitive to context and capable of incorporating challenging urban contexts, such as those in the Global South. The participatory nature of MCA enables stakeholders to provide input for democratic decision making. This is important for complex issues that impact society at large, including BGI, as stakeholder engagement can strengthen the MCA quality, transparency and legitimacy. In other words, MCA is well equipped to address the complexities of planning for a WSC with BGI.

MCA can be supported using value-focused approaches (Section 2.8). Value-focused approaches emphasise values (principles, goals or aims) as the fundamental component of planning, rather than alternatives or options. They start with an articulation of values, prioritising first on what is desired rather than on the set of pre-defined alternatives. This allows for a strategic and proactive approach, improving planning by articulating upfront what is important (Figure 15). Once values are defined, the options are created as a means to achieve the values. The criteria are then selected to reflect the values and objectives to be achieved.

With MCA established as a suitable basis, four key factors were seen as important to the method for this research:

- (1) the city scale of evaluating the potential for existing BI to provide multiple benefits as BGI,
- (2) the method should be value-focused and strategic for WSC planning, allowing for flexibility to incorporate multiple benefits and contextual factors,
- (3) the method should be structured, transparent and understandable, to allow for transferability to support WSC planning, and
- (4) the method should be participatory, with capacity for stakeholder involvement.

The following two tools that use multi-criteria approaches were initially considered for the research: the Blue-Green Cities Multiple Benefits Toolbox and the Green Infrastructure Spatial

Planning model (Blue-Green Cities, 2017; Meerow & Newell, 2017) (Table 5). These tools however use fixed methods that did not satisfy all four key factors that were seen as important to the method. The Green Infrastructure Spatial Planning model accounts for the city scale while both tools provided for stakeholder participation via weighting at one stage in the MCA; both tools are structured and transparent. However, they both used predetermined criteria without the flexibility to incorporate benefits strategically in line with the vision of a WSC. Furthermore, they were developed initially for Global North contexts and did not adequately consider Global South complexities. Therefore, this research developed an MCA methodology to satisfy the four key factors.

3.2 Developing a multi-criteria analysis

The weighted additive model was selected as the MCA technique. This model is classified as a simple MCA method which calculates the overall performance of options and indicates what the ‘best’ option is (Dean, 2022) (Figure 14). The weighted additive model has been widely used in BGI and WSC planning and evaluation studies (e.g., Kremer *et al.*, 2016; Meerow & Newell, 2017; Morgan & Fenner, 2019; Goodspeed *et al.*, 2021; van Oorschot *et al.*, 2021). A large part of their appeal is their ease of use, which means they are understandable, to allow for transferability to support WSC planning. Hajkowicz & Higgins (2008) note that highly sophisticated techniques are not always necessary. The authors emphasise the ease of understanding a technique so that it can provide planning and decision support.

A value-focused approach was adopted as part of the method (Keeney, 1992, 1994, 1996). This allowed for the strategic identification of benefits in line with the vision of a WSC. The city scale of the research specified the boundaries of the system as the City of Cape Town (CCT). The scope was defined as that of a ranking problem which compares different options and places them in a form of preference ordering (Keeney, 1992; Roy, 1996). The need for a participatory method meant that stakeholder involvement at multiple key points was incorporated. The selection and scoring of criteria were undertaken in a manner sensitive to the Global South context of Cape Town.

The research method followed the key steps of an MCA (Section 2.9). It was developed through the case study of evaluating the potential of existing stormwater ponds to provide multiple benefits as BGI in Cape Town. The steps are outlined below, and detailed in the subsequent chapters (Figure 20):

- A literature review was conducted, with a focus on two areas: (1) the concepts of WSCs and BGI, and associated planning, with specific attention to urban Global South contexts, and (2) MCA methods and the key MCA steps, with examples from BGI planning to explain each step.
- Objectives were identified and structured through value-focused thinking in line with the vision of a WSC with BGI. They were identified through benefits provided in a WSC and

by BGI, as discussed in the literature review (Chapter 2). The objectives were structured as fundamental objectives of a WSC and framed as WSC planning priorities. The adapted ‘five Ws of a WSC’ framework (Meerow *et al.*, 2016; Meerow & Newell, 2019) supported this step and was applied to consider BGI for who, what, when, where and why.

- Cape Town, RSA was used as a case study as it has committed to become a WSC by 2040. Moreover, it has a history of engaging with the WSC concept in policy and planning since 2009. It is grappling with various typical Global South water management and planning challenges alongside various social and economic issues.
- The selection of existing stormwater ponds as the BI options was explained. The process of obtaining and refining a stormwater ponds dataset was described. This included a semi-structured interview with a CCT official in asset management, and ground-truthing the dataset using GIS and satellite imagery. A dataset refined from 1016 to 848 stormwater ponds was produced for the subsequent MCA steps.
- A pilot MCA was conducted on Cape Town’s stormwater ponds using five WSC planning priorities (objectives), and associated criteria. It was based on pre-processed and publicly available datasets, literature and the author’s judgement, without stakeholder input. The pilot MCA was used to refine the WSC planning priorities (objectives) and inform the criteria for the final MCA. It provided a tangible example for stakeholders to engage with during the semi-structured interviews.
- Semi-structured interviews with WSC experts were conducted with seven professionals engaged in work on WSCs, GI, BGI and resilience at a strategic city-wide level in Cape Town. They were used to refine the WSC planning priorities and inform the selection of relevant contextual criteria and datasets for the final MCA. Moreover, they provided general input on the options and performance scoring. The interviews were either in-person or virtual and lasted around one hour in length.
- Seven criteria were selected, with one criterion selected for each of the seven WSC planning priorities for the final MCA. Datasets linked to each criterion were acquired and processed for scoring. The datasets were either derived from, or were, secondary datasets, in both spatial and non-spatial format. The spatial datasets were in both vector and raster format, with the majority in vector format. Publicly available and/or pre-processed datasets were favoured.
- Performance scoring was undertaken to measure the performance of each option (stormwater pond) against the seven criteria for the final MCA. A proportional scoring approach with an interval scale of zero (worst performance) to one (best performance) in a linear form was used. Microsoft Excel, Quantum GIS (QGIS) and ArcGIS Pro were used for data processing and scoring. In GIS, spatial queries and associated tools (primarily the ‘Join Attributes by Location (Summary)’ tool) were used to extract criteria data, which was then scored in Microsoft Excel. GIS was also used to individually map the seven criteria.

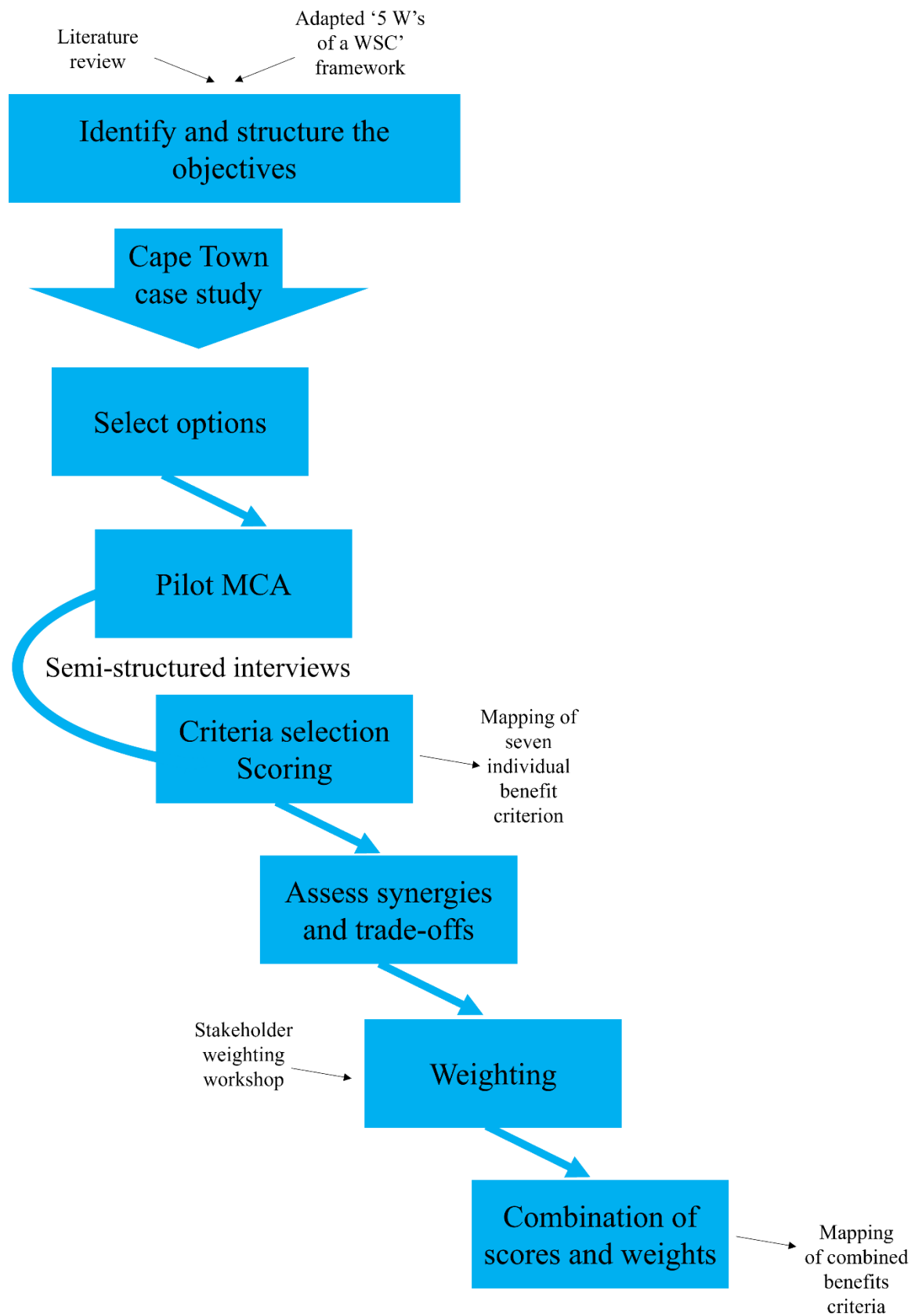


Figure 20: The research method

- Synergy and trade-off patterns were assessed by calculating the Pearson correlation coefficient between criterion scores. A positive correlation indicated a synergy, and a negative correlation indicated a trade-off between two criteria.
- The seven WSC planning priorities and their associated criterion were weighted by 19 stakeholders at a workshop session for the final MCA. Three weighting methods of ranking, rating and pairwise comparisons were used. The weightings from the ranking method were calculated using the rank sum method (Malczewski & Rinner, 2015). The pairwise comparisons weightings were calculated using a Microsoft Excel based AHP calculator developed by Goepel (2013).
- The scores and weights were combined using Equation 1 to calculate the overall suitability scores in Microsoft Excel for the final MCA. The scores were calculated from the three sets of stakeholder derived weights (ranking, rating and pairwise comparisons) along with an equal weighting scenario. The stormwater pond multifunctional potential rankings from the four weightings were visualised through mapping on GIS.
- The results are discussed in Section 9.4 and 9.5. This discussion covers the application and outputs of the MCA methodology to existing stormwater ponds in Cape Town and insights from the process of developing the MCA methodology.

3.3 Limitations

The following limitations were identified:

- The city scale of the MCA methodology that was developed was intended to be high level rather than a detailed site scale analysis with designs and costing. For example, the land use and physical characteristics such as size or vegetation types of the stormwater ponds was not considered. Neither were the site-specific relevant dominant benefits at each pond that might be used to prioritise how individual criteria address local benefit needs, although this is easily done with the MCA if required. The level of detail of the criteria and the spatial resolution of datasets was influenced by the city scale.
- The application of the MCA methodology was limited to the existing BI of stormwater ponds in Cape Town. Relevant contextual criteria were selected for this type of existing BI. The MCA methodology does not assist with identifying existing BI for evaluation. Furthermore, if other types of existing BI were evaluated, other or additional criteria may need to be included.
- The WSC concept is multidimensional and qualitative in nature and there is inherent subjectivity in translating it into objectives and criteria.
- There is inherent subjectivity associated with performance scoring of the options in their contribution to achieving the objectives and criteria – even though the scores are assigned

based on the best and worst performing options in the datasets.

- Stakeholder derived weighting was obtained with three weighting methods during a workshop with 19 stakeholders. The mean stakeholder weightings were used to calculate the overall rankings. This was to get a range of various interests and values; however, this is only a representation and was limited by the number of stakeholders and their affiliations, as well as the averaging that was used. Furthermore, there are limitations associated with assigning relative importance to multiple objectives (Dean, 2022). It becomes progressively more difficult as the number of objectives increases.
- The research depends on data from, or derived from, secondary datasets, with pre-processed and publicly available datasets favoured. The spatial and temporal resolution, as well as the accuracy, is dependent on the characteristics of the datasets. This research used over fifteen secondary datasets. Each dataset was checked, and a number of datasets were refined for use in the analysis, in line with the scope and scale of the study and practical limitations of the research. Some datasets were checked through conversations with relevant stakeholders such as culture and heritage related datasets, and the stormwater ponds dataset and the parks in Cape Town dataset were refined. Chapter 8 discusses the various datasets that were used in the research.
- This study used aggregated spatial datasets at different spatial and temporal resolutions and scales. For example, the 2011 census data had census tracts (vector polygons), and the 2020 South African national landcover dataset had a raster grid of 20 x 20 m (Statistics South Africa, 2011; Department of Forestry Fisheries and the Environment, 2021). There are limitations associated with this, often referred to as the ‘Modifiable Areal Unit Problem’ in the literature (Openshaw & Taylor, 1979; Dark & Bram, 2007; Li *et al.*, 2018; Buzzelli, 2020).
- The concepts of WSCs and BGI need to consider issues of equity for Global South contexts. This research acknowledges and discusses issues of equity that characterise the South African context, and many Global South contexts, throughout the chapters. For example, issues of equity are explicitly discussed in the literature review (Chapter 2), the description of Cape Town (Chapter 4) and the expert semi-structured interviews (Chapter 7), amongst the others. However, equity is not included in a measurable criterion with performance scoring in this research. For example, equity could be included in a measurable criterion by prioritising various benefits for minority and vulnerable groups through performance scoring. Identifying minority and vulnerable groups, and then obtaining value judgements to incorporate their prioritisation and scoring for various benefits, is extremely complex, political and nuanced. RSA is still grappling with significant issues of inequality since institutionalised racial segregation (called ‘Apartheid’) formally ended in 1994, and the identification of marginalised groups is highly sensitive and political. It was beyond the scope of this research to undertake work of this nature. Furthermore, spatial scale impacts equity assessments, with indicators prone to skewness (Sister *et al.*, 2010; Zhang *et al.*, 2011; Rigolon, 2016; Tan & Samsudin, 2017). Tan & Samsudin (2017) note that ‘..there

are still inconsistencies and uncertainties in how geographic access to such benefits are correlated to race and socio-economic status (SES) (used here to refer to the combined effects of wealth, income, education, and occupation on social standing), which weakens the evidence base for effective policy interventions to address equity issues’. In the case of parks in equity mapping studies, Rigolon (2016) explains that *‘the evidence is mixed about how access to any park, expressed in terms of distance between homes and the closest park, varies by socio-economic status, and ethnicity/race. Thus, the numeric analysis of park proximity shows that ethnic minority groups might have better access to parks than whites and no evident inequities in terms of socio-economic status’.* It was beyond the scope of this research to include equity through a measurable criterion in a rigorous and sensitive enough manner for the scale of this research, i.e., the scale of the CCT.

- This research focused on developing an MCA methodology through evaluating the potential for stormwater ponds to provide multiple benefits, beyond stormwater management, as BGI in Cape Town. The stormwater ponds in Cape Town were designed for a stormwater management function, with a high-level research study undertaken by Behardien (2021) approximating that around 96% of the ponds fulfil this function (Appendix A). This research was undertaken for an Honours level Bachelor of Science (BSc) (Engineering) dissertation designed and co-supervised by the author. Furthermore, the expert semi-structured interviews conducted in Chapter 7 confirmed the existing stormwater management function of the ponds. Considering this, stormwater management is not included as a criterion in this study, like it is in many studies evaluating multifunctionality. Such studies often use criteria such as percent impervious surface, mean runoff co-efficients, stormwater absorption base on Curve Numbers and percentage of rain absorbed in a pixel (Kremer *et al.* 2016; Meerow & Newell, 2019).
- There are significant cost implications to realise the multi-functional potential of stormwater ponds. However, given the complexity of estimating costs, it was considered to be outside the scope of this study.

3.4 Identifying and structuring objectives

This research used value-focused thinking. Values are made explicit by the identification of objectives. This process is guided by the decision context and questions such as ‘what is to be achieved or provided for in this situation’. Value-focused thinking assists with developing objectives that are strategic in nature. Keeney (1992) emphasises the critical importance of identifying and understanding objectives stating, *‘if you really care about a decision, objectives are worth deep and serious thought’.* Indeed, the achievement of objectives is the primary driver for decision making and planning. Good planning and decision making needs clear objectives that are specific, strategic, measurable and realistic (Dodgson *et al.*, 2009). There are three characteristics of objectives: a decision context, an object and a direction of preference (Keeney, 1996). Objectives are usually qualitative in nature.

Value-focused thinking distinguishes between the concepts of fundamental objectives and means objectives (Section 2.8). Keeney (1994) explains that ‘*fundamental objectives concern the ends that decision makers value in a specific decision context; means objectives are methods to achieve an end*’. Fundamental objectives perform the essential work of strategically guiding planning and evaluating the alternatives. Means objectives can assist with an approach to analysing problems and creating alternatives.

For this research, value-focused thinking was used in accordance with the vision of a WSC with BGI. The identification of objectives was supported by the adapted ‘five Ws of urban resilience’ (whom, what, when, where, and why) framework (Meerow & Newell, 2019) (Table 2) and the questions proposed by Keeney (1996) (Table 4). Both fundamental and means objectives were selected. Table 6 provided the list of questions that informed the development of objectives. Indeed, the established WSC and BGI principles themselves provided an ‘*explicit set of objectives that the decision making body has identified*’ (Dodgson *et al.*, 2009). The ‘what’ and ‘why’ questions pertained largely to the development of objectives for a WSC. The ‘who’, ‘when’ and ‘where’ questions primarily assisted with selecting criteria and informing options.

Table 6: Questions to consider for a WSC with BGI

		Questions to consider	
Identifying and structuring objectives for WSC benefits	Why?	TRADE-OFFS	What are the goals of transitioning to a WSC – why a WSC?
			What are the underlying reasons for transitioning to a WSC?
			Is the focus on process or outcome?
	What?		What is wanted and valued in a WSC?
What WSC objectives should be included?			
What are the aspirations for and limitations to providing benefits in a WSC?			
What features and sectors (social, ecological, technical) are included in the city?			
Selecting criteria for benefits provided by BGI in a WSC	Who?	OFFSETS	Who benefits from the WSC and BGI functions?
			Whose benefits are prioritised?
	Where?		Where are the spatial boundaries of the city?
			Are some areas prioritised over others for benefits?
		Does providing benefits in some areas affect others?	
	When?		Is the focus on achieving benefits for the short- or long-term?
			Is the focus on rapid onset shocks or gradual changes?

Seven fundamental objectives were selected that represented commonly cited benefits of a WSC from the literature (Section 2.2): (1) ‘Enhancing cultural and heritage associations with water systems’, (2) ‘Increasing water re-use’, (3) ‘Reducing climate change impacts’, (4) ‘Utilising educational services potential’, (5) ‘Increasing access to blue-green space’, (6) ‘Incorporating

stormwater quality limitations’, and (7) ‘Enhancing biodiversity’. These fundamental objectives were framed as WSC planning priorities. The means objective was informed by the literature on BGI multifunctionality (Section 2.3) and defined as using BGI as a means to achieve the fundamental objectives of a WSC.

In selecting the objectives, consideration was given to the theory and principles of a WSC, and the related benefits and functions. In particular, the socio-political drivers and service delivery functions of the Urban Water Management Transitions Framework (Figure 5) and the three pillars for practice provided a range of WSC characteristics. For example, climate change resilience, biodiversity and public green space. Moreover, the ‘Water Sensitive City Index’ was used to develop the objectives as it articulates goals and indicators of a WSC, for example ‘groundwater recovery and replenishment’ and ‘cultural and community connections with water systems’ (Figure 6).

Planning for WSCs in a Global South context was considered, drawing on Section 2.4. This was to provide insights on different needs and constraints in these contexts such as the limitations of poor water quality and informality. For example, the evolution of the WSUD and WSC concepts in RSA (Section 2.5) as well as the ‘Water Sensitive City Index’ adapted for RSA (Figure 2) provided input to the objectives. While objectives need to reflect a desired state, they also need to incorporate limitations or constraints for a planning problem.

The WSC planning priorities were investigated in relation to BGI after the fundamental and means objectives were defined. The questions in Table 6 were applied to the means objective, considering BGI for when and where, with the question of what also included to critique the planning priorities. The questions allowed for the breadth of WSC objectives and BGI benefits to be explored. They enabled all relevant and potential elements to be considered before the scope was narrowed by selecting criteria and options. The responses considered all possibilities under each question. They highlight how an emphasis on different choices, or combinations of choices, impact what is measured (through the criteria), which areas in a city are prioritised (trade-offs) and who benefits as a result (Table 7).

Various potential criteria are proposed in Table 8. The proposed criteria were organised under the WSC priorities. They were a starting point to build from and refine based on the case study context and options.

3.5 Summary

This chapter described the method used to construct an appropriate MCA methodology to evaluate the potential for existing BI to provide multiple benefits as BGI using a case study of existing stormwater ponds in Cape Town.

After outlining the method steps, seven fundamental objectives corresponding to commonly cited benefits of a WSC were identified.

Table 7: The five W's of a WSC applied to the seven WSC planning priorities

WSC planning priority	What	When	Where	Why
Enhancing cultural and heritage associations with water systems	Spaces near heritage and cultural resources may contribute to establishing water associations.	Focused on current culture and heritage resources.	Potential BGI near heritage and cultural resources.	Goal is an outcome: increased cultural and heritage associations with water systems.
Increasing water re-use	Rainwater or stormwater harvesting. Surface or sub-surface storage of water for re-use.	Focused on current water re-use.	Suitable conditions for water harvesting and re-use.	Goal is an outcome: increased water re-use, increased aquifer recharge and decreased pressure on potable network demand.
Reducing climate change impacts	UHI effect mitigation. Carbon sequestration.	Both short and long term.	Areas with high land surface temperatures. Citywide carbon sequestration.	Mitigating and reducing climate change impacts.
Utilising education services potential	Focused on education opportunities connected to urban biodiversity and the general water system.	Focused on current beneficiaries.	Schools near potential BGI.	Enhanced opportunities to use BGI in education.
Increasing access to blue-green space	Increased blue-green space amenities. Increased access to blue-green space amenities.	Both short and long term WSC amenity objective.	People within a defined radius of potential BGI. People with the lowest mean access to blue-green space, within walking distance to potential BGI.	Goal is an outcome: Increased number of blue-green amenity spaces, as well as increased access to the spaces.
Incorporating stormwater quality limitations	Considering land covers or activities with adverse stormwater quality.	Focused on current stormwater quality issues.	Potential BGI near known pollution sources.	Goal is an outcome: incorporation of stormwater quality limitations for people and the environment, impacting water re-use potential, public health and amenity.
Enhancing biodiversity	Increased conservation. Increased landscape connectivity. Increased habitat size and structure.	Both short and long term WSC objective.	Biodiversity and conservation significance.	Goal is an outcome: Increased urban biodiversity.

Table 8: Potential criteria categorised under the WSC planning priorities

WSC planning priority	Potential criteria
Enhancing cultural and heritage associations with water systems	Proximity to culture and heritage resources.
Increasing water re-use	Stormwater harvesting potential, storage, aquifer presence and type, transmissivity, soil type, geology.
Reducing climate change impacts	Mean land surface temperature for three months (using Landsat or MODIS), windspeed and direction, carbon sequestration rate based on landcover.
Utilising education services potential	Proximity to school.
Increasing access to blue-green space	Estimate of tract population without access to parks, mean population density in 500 m radius, population weighted distance to nearest park using road network.
Incorporating stormwater quality	Proximity to informal settlement, proximity to WWTW, service provision levels such as frequency of street sweeping and garbage collection.
Enhancing biodiversity	Biodiversity or conservation significance, Patch cohesion Index, habitat size.

These objectives were structured as WSC planning priorities. The specified means objective of BGI was explored, considering benefits for what, when, where and why in a WSC. The chapter closed with proposing potential criteria, which are developed in the following chapters for application in the case study context of Cape Town, RSA.

4. Case study context: Cape Town, South Africa

Seven WSC planning priorities were selected as objectives for the MCA methodology (Section 3.4). The objectives needed to be placed in a specific socio-economic and institutional context, place, time and scale to give them expression (Albrechts, 2004). The City of Cape Town (CCT), RSA was selected as a suitable case study context. It has committed to become a WSC by 2040 and is grappling with the associated planning and implementation challenges. This chapter describes the city, starting with a general description and moving onto its journey with the concepts of WSUD and WSCs in policy and planning.

4.1 General description of the City of Cape Town

The CCT is located on the Southwestern tip of RSA (Figure 21). It had a population of approximately 4.8 million people with around 1.3 million households in 2021. Approximately 79.1% of the households lived in formal dwellings, 7.3% of households lived in informal dwellings in the backyards of formal dwellings and 14.4% of households lived in informal dwellings that were not in backyards (Western Cape Government, 2021). Examples of these dwelling types are illustrated in Figure 23 to Figure 25. The city is highly socio-economically unequal and spatially segregated, with the urban fabric contrasted with affluent suburban sprawl and dense informal settlements (Scheba *et al.*, 2021). The city has a relatively small Central Business District (CBD).

Citizens have varying levels of access to water services, with households living in informal dwellings typically having limited access to basic services, with communal, and often dysfunctional, water and sanitation facilities and limited drainage infrastructure and solid waste removal (Jiusto & Kenney, 2016). Basic water and sanitation services are a human right afforded under the South African Constitution; however, drainage services are not (Armitage, 2011; Jiusto & Kenney, 2016). The reported access to basic services in the city is 96.4% for piped water inside or within 200 m of the dwelling, 90.9% for a flush or chemical toilet, 93.7% for electricity and 94% for solid waste removal at least weekly (Western Cape Government, 2021). However, the politics of access impact these figures negatively (Carden, 2013).

There is competition for land in the city, with growing urbanisation levels and people seeking housing closer to work opportunities. The city is expanding and densifying, with the latter at a faster rate than the former. Increasing patches of informality contribute to the growth (Scheba *et al.*, 2021). The development of informal settlements often occurs on open and undesirable land. This land typically has no formal development because of its unsuitability, such as floodplains, stormwater ponds and depressions, steep slopes and proximity to the airport (Armitage, 2011). The use of such areas for informal housing pose flooding risks and public health concerns (Mclachlan *et al.*, 2023).

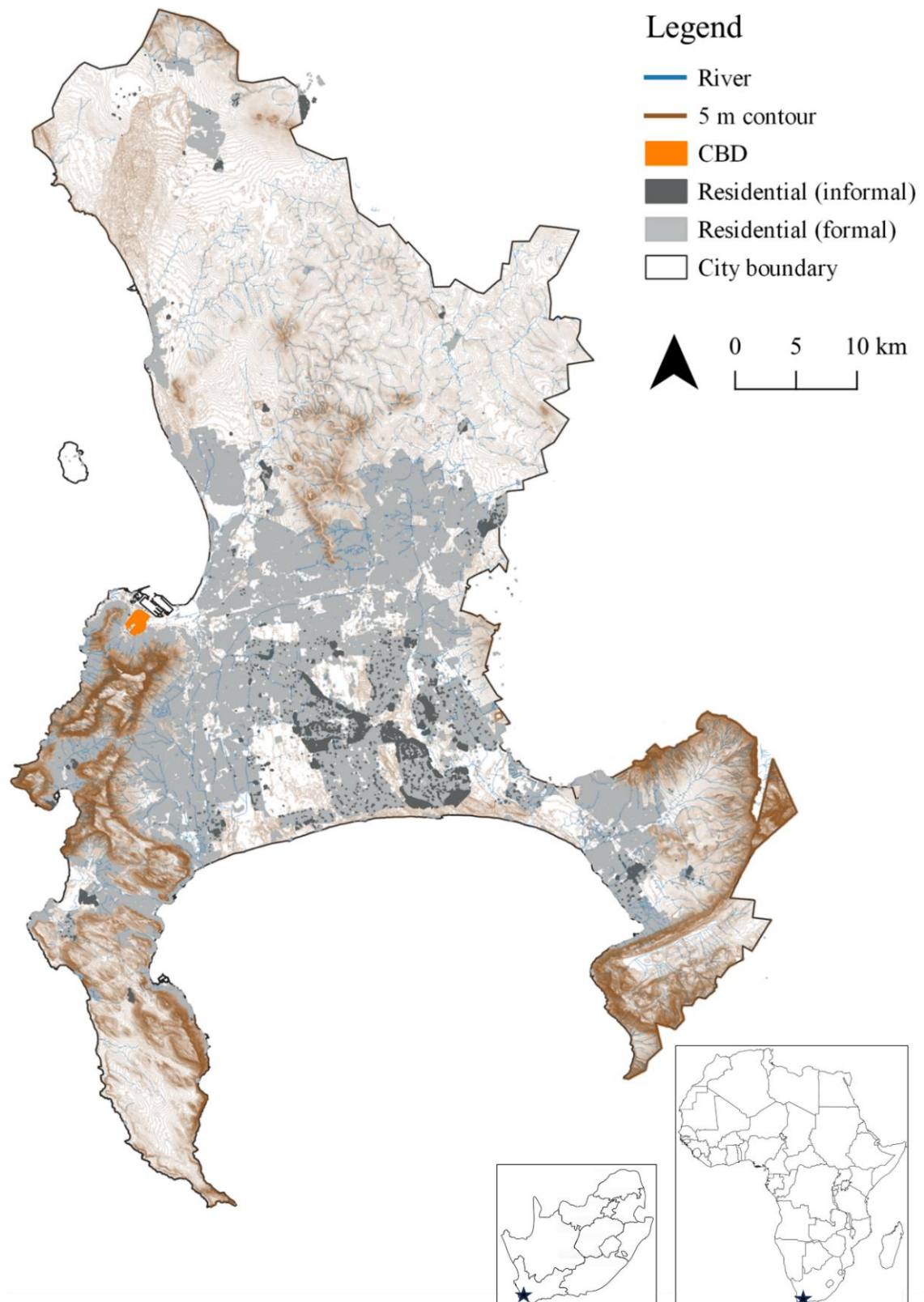


Figure 21: The location and landcover in the CCT (City of Cape Town, 2019c, 2019d; Department of Forestry Fisheries and the Environment, 2021)



Figure 22: CCT viewed from the harbour (City of Cape Town, 2017)



Figure 23: An example of formal social housing blocks next to an area of informal housing (Department of Human Settlements, 2004)



Figure 24: An example of formal housing (Department of Human Settlements, 2004)



Figure 25: An example of an informal settlement with stormwater drainage challenges

Cape Town has a mild Mediterranean climate with wet winters and warm dry summers. It receives an mean annual rainfall of approximately 500 mm; however with a large spatial and temporal distribution (City of Cape Town, 2018). Most of Cape Town's rainfall is received in the winter months with 70% of rainfall concentrated between May and October, with June and July usually the wettest months. Climate change is projected to impact Cape Town in a number of ways including: a significant decrease in mean annual rainfall, changed seasonality of rainfall, a significant increase in the mean annual temperature and maximum temperatures, more high heat days (higher than 35°) and frequent and intense heat waves, an increase in wind strength and a rise in mean sea level and increased coastal erosion (Petrie *et al.*, 2019).

Cape Town relies on surface water from the Western Cape Water Supply System (WCWSS) for approximately 96% of its water. This regional integrated surface water system is managed by the South African Department of Water and Sanitation in partnership with the CCT, neighbouring municipalities, and agricultural users. The WCWSS consists of six large rain-fed dams and a number of smaller ones, with a total storage of approximately 900 million kilolitres (900 gegalitres) (City of Cape Town, 2020b). The dams primarily fall outside of the CCT boundaries, but their catchment areas all fall in the Western Cape's winter rainfall region. The CCT uses approximately 64% of the water, agriculture uses 29%, while the other towns use the remainder. The reliance on surface water is projected to change, with the city's future water resource mix potentially comprising of 75% surface water and 25% from a combination of groundwater, desalination and re-use by 2040 (City of Cape Town, 2020b).

Cape Town has many of the complex water challenges common to Global South cities such as water resource shortages, deteriorating water infrastructure, climate and land use changes, and weak institutional and governance capacity (Rouault & Richard, 2003; Carden *et al.*, 2016). These water management and planning issues occur alongside other social, political and economic factors such as high unemployment rates, serious housing shortages and municipal budget constraints (Scheba *et al.*, 2021; Western Cape Government, 2021). Similar to other urban areas in RSA, Cape Town largely relies on conventional centralised water management and planning approaches, with siloed municipal departments (City of Cape Town, 2020).

In RSA, three spheres of government are involved in water affairs: (1) the Department of Water and Sanitation who are responsible for water resources and bulk management, (2) provincial government who provide a supportive role to local government and agriculture, and (3) local municipalities who are responsible for supply infrastructure and service delivery (Taing *et al.*, 2019). Within RSA municipalities, stormwater is traditionally managed as part of the roads department with a separate water and sanitation department. In the CCT however, more visionary and holistic approaches have resulted in the Catchment, Stormwater and River Management Branch being shifted to the Department of Water and Sanitation.

4.2 Water infrastructure

CCT relies on the centralised treatment and provision of water services, with a large asset base comprising: 12 water treatment plants with a combined capacity of 1600 ML/day, 24 reservoirs for treated water with a minimum of 48-hour storage capacity, and 11,000 km of water pipes. With regards to sewerage, the CCT operates 23 wastewater treatment works (WWTWs) with a combined capacity of close to 740 ML/day, fed by 9000 km of sewer pipes. In informal settlements, which comprise 12% of CCT households, there are 6500 communal taps and 50,000 onsite and offsite sanitation toilets (City of Cape Town, 2020b).

The CCT listed their stormwater management system in 2021 as a network of built and natural infrastructure including 150,000 gullies/intakes, 16,630 km of pipes and culverts, 890 stormwater ponds, 236 stormwater treatment wetlands, 1910 km of rivers and streams, thousands of wetlands including ‘vleis’ (small shallow lakes), 27 stormwater pump stations, 59 rainfall and flow monitoring stations, and approximately 200 inland and coastal water quality monitoring stations valued at R22 billion (City of Cape Town, n.d.-b). Traditionally, stormwater management has been primarily focused on flood control and the management of quantity, but this is changing as the CCT embraces the principles of WSC and SuDS (City of Cape Town, 2020b). Cape Town’s urban waterways are a component of the urban biodiversity, with the city said to be one of the most biodiverse cities in the world (Day *et al.*, 2021). There are many green spaces in the city, with the CCT managing 20 nature reserves, 14 district parks, 354 greenbelts, 307 km of coastline, more than 45,000 ha of protected areas (nature reserves) and 21 main river catchments (City of Cape Town, 2022b).

Poor water quality is a major concern in the city, with some of the challenges detailed in the CCT publication ‘*2019 Inland Water Quality Report: Guiding the transition to a water-sensitive future*’ (City of Cape Town, 2019o). Alongside a few catchments in a relatively good state, there are many catchments that face elevated levels of nutrients (phosphorus in particular), low oxygen levels and bacterial contamination. Stormwater from all land uses including residential, commercial, and industrial is a significant contributor to the water quality problem. Furthermore, household waste, greywater and sewage also enter the stormwater system, primarily from informal settlements and backyarder dwellings, due to poor service delivery.

4.3 Water sensitivity in policy and planning in Cape Town

Cape Town has been formally engaging with the concepts of WSUD and WSC since 2009 when it first appeared in policy. Over the next decade, the city increasingly integrated the principles into various policies, plans and strategies. Then there was an extreme drought and associated ‘Day Zero’ crisis (Ziervogel, 2019). The drought was the worst on record since 1904 and was caused largely by below average rainfall over 2015 to 2017, that might well be linked to climate change (Otto *et al.*, 2018; Wolski *et al.*, 2020). This all culminated in an explicit commitment to ‘*become a Water Sensitive City*’ by 2040 in its 2020 water strategy titled ‘Our Shared Water

Future: Cape Town's water strategy' (City of Cape Town, 2019b; City of Cape Town, 2020b; Carden & Fell, 2021).

Prior to the water crisis, water sensitivity was slowly gaining traction in policy. Its first appearance was in the 2009 CCT Floodplain and River Corridor Management Policy and the 2009 CCT Management of Urban Stormwater Impacts Policy (City of Cape Town, 2009a, 2009b). Both policies were developed by the then Catchment, Stormwater and River Management Branch in the Roads and Stormwater Department. This reflected the broader international trend of WSUD's initial association with stormwater (Brown *et al.*, 2016). The policy statement for the CCT Management of Urban Stormwater Impacts Policy stated '*In order to reduce impacts of urban stormwater systems on receiving waters, all stormwater management systems shall be planned and designed in accordance with best practice criteria and guidelines laid down by Council, to support Water Sensitive Urban Design principles*'. Both policies focused on reducing the impact of flooding and managing stormwater for the health of waterways using WSUD.

The CCT Urban Design Policy advocated for WSUD principles in 2013, stating '*Start the design process by understanding and working in harmony with the natural drainage patterns of the site and apply the principles of Water Sensitive Urban Design so as to arrive at a layout that is water sensitive and space efficient, minimises the disruption of the natural hydrological cycle and works together*' (City of Cape Town, 2013). Once again, WSUD was largely framed as a drainage related field, however there was acknowledgement of multifunctional aspects. This policy was developed with a range of departments including Transport, City Parks and Planning and Building Development Management. The inclusion of WSUD principles in this policy marked a milestone for WSUD in Cape Town, where other departments, besides Water and Sanitation, began embracing WSUD.

The 2017 CCT Climate Change Policy made multiple references to committing to use WSUD principles to strengthen water resilience, assist with disaster risk management policies, diversify water sources and ensure '*climate compatible urban design and infrastructure development and maintenance*' (City of Cape Town, 2017). However not much detail was given beyond the mention of these water sensitive aspirations.

The 2017 CCT Water Services Development Plan – Integrated Development Plan Water Sector Input Report articulated a vision '*to be a beacon in Africa through the progressive realisation of Cape Town as a water sensitive city*' (City of Cape Town, 2017). Climate change was cited as a major reason for the paradigm shift to water sensitivity. The plan included the role of alternate water sources to realise a WSC and the principles of using the city as a catchment. It was mostly focused on resource and infrastructure management and service delivery.

The Western Cape Sustainable Water Management Plan (2017–2022) included WSUD as one of 12 focus areas. Furthermore, it promoted the use of WSUD approaches throughout, including water re-use, aquifer recharge through SuDS, infiltration of stormwater and the diversification of water sources to improve water and climate change resilience at all scales

(Western Cape Government, 2018).

The 2019 CCT Resilience Strategy referenced WSUD in three actions: (1) Rejuvenate our rivers and the spaces around them to create liveable urban waterways, (2) Enhance partnerships for improved water governance and holistic water resilience, and (3) Determine progress towards attainment of improved water resilience. It largely focused on waterways and water quality aspects of a WSC (City of Cape Town, 2019a).

The 2020 Cape Town Water Strategy represented the most significant commitment to a WSC (City of Cape Town, 2020b) to date. The water strategy outlines five commitments to its citizens including: (1) safe access to water and sanitation, (2) wise use, (3) sufficient reliable water from diverse sources, (4) shared benefits from regional water resources, and (5) a WSC (Figure 26). The fifth commitment states that the CCT will ‘*..actively facilitate the transition of Cape Town over time into a water-sensitive city with diverse water resources, diversified infrastructure and one that makes optimal use of stormwater and urban waterways for the purposes of flood control, aquifer recharge, water reuse and recreation, and that is based on sound ecological principles. This will be done through new incentives and regulatory mechanisms as well as through the way the City invests in new infrastructure*’. Through this commitment, the CCT is explicit in its specified objectives and priorities for translating and implementing the WSC concept in the city. The strategy emphasises the opportunity presented by the stormwater challenge in Cape Town – pollution, low amenity and liveability value, a lack of safety, a lack of use of built and natural stormwater systems and potential for water re-use.

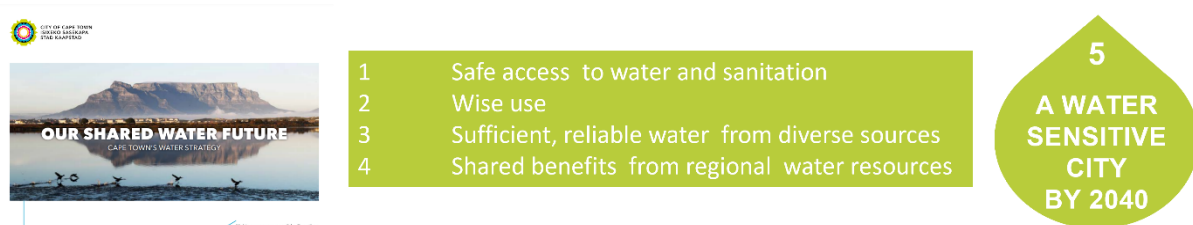


Figure 26: The five commitments of the Cape Town 2020 Water Strategy

A number of the policies, plans and strategies discussed in this section that reference water sensitivity are illustrated on the timeline in Figure 27, developed in a review of water sensitivity in policy by Carden & Fell (2021).

The 2021 CCT Climate Change Action Plan aligned two of its ten developed strategic focus areas (SFA) on water sensitivity; with one SFA focused on urban cooling and heat responsiveness with an action to devise and implement an urban greening programme to reduce the heat island effect. Another SFA emphasised water sensitivity, flood readiness and storm management, with an action to develop and implement a WSC strategy or plan and to restore and rehabilitate the City’s rivers and wetlands to create liveable urban waterways (City of Cape Town, 2021).

The increasing emphasis on water sensitivity in policy, and the multiple disciplinary and department perspectives and priorities, highlight the CCT's WSC values and objectives from multifunctional infrastructure to water re-use to UHI effect reduction to recreation.

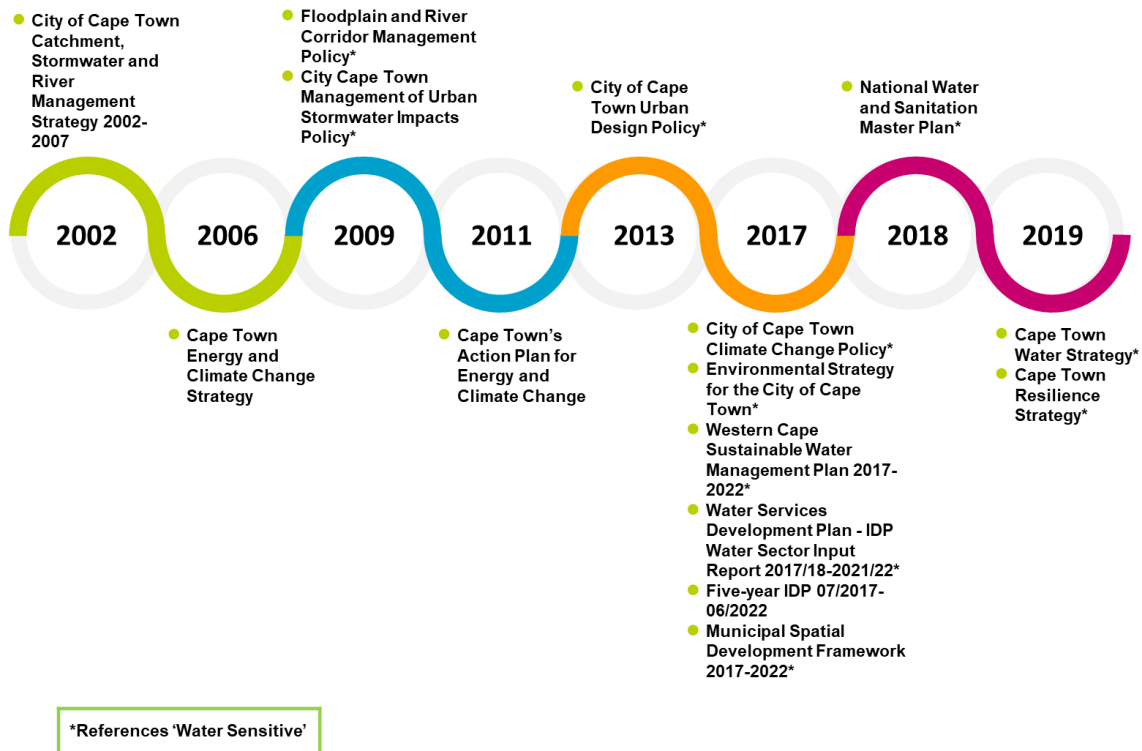


Figure 27: Timeline of selected water policy in Cape Town (Carden & Fell, 2021)

4.4 Benchmarking the City of Cape Town as a Water Sensitive City project

One of the first steps in delivering on the CCT's commitment to '*become a Water Sensitive City*' by 2040 was through the 'Benchmarking the City of Cape Town as a Water Sensitive City' project (Fell & Carden, 2021). The project was commissioned by the Western Cape Government: Department of Environmental Affairs and Development Planning and the City of Cape Town Metropolitan Municipality. It was undertaken from 2020 to mid-2021 by Zutari (Pty) Ltd, in partnership with the University of Cape Town's Future Water Institute and the Cooperative Research Centre for Water Sensitive Cities (CRCWSC) based in Melbourne, Australia. The three project phases comprised: (1) benchmarking the CCT's water sensitive performance with an adapted version of the 'Water Sensitive City Index' (Zutari, 2020b), (2) developing a water sensitive vision for Cape Town (Zutari, 2021a), and (3) transition planning and strategy development (Zutari, 2021b). The author was a part time embedded research on the project, which contributed to parts of the conceptual foundation of this research.

The first benchmarking phase used the ‘Water Sensitive Cities Index’, which is based on the UWMTF (Figure 5). The ‘Water Sensitive Cities Index’ (Figure 6) was developed largely based on the Australian context by the Cooperative Research Centre for Water Sensitive Cities in Australia. It was adapted for the South African context through specifying that 16 out of the 34 indicators needed to be rated separately for the formal and informal areas of the city being benchmarked (Figure 2). As a result, the ‘Water Sensitive Cities Index’ had three sets of results for (1) formal areas, (2) informal areas, and (3) Cape Town overall. For 16 indicators, the weighted mean rating was determined from the percentage of households in formal (87% of households) and informal (13% of households) areas while the remaining 18 indicators were rated citywide. The indicators that are relevant to the MCA objectives of this research are outlined in red in Figure 28 (Zutari, 2020b).

Socio-Political Goals				Bio-Physical Goals		
1. Ensure good water sensitive governance	2. Increase community capital	3. Achieve equity of essential services	4. Improve productivity and resource efficiency	5. Improve ecological health	6. Ensure quality urban space	7. Promote adaptive infrastructure
1.1 Knowledge, skills and organisational capacity	2.1 Water literacy	3.1 Equitable access to safe and secure water supply	4.1 Benefits across other sectors because of water-related services	5.1 Healthy and biodiverse habitat	6.1 Activating connected pleasant urban green and blue space	7.1 Diverse fit-for-purpose water supply system
1.2 Water is key element in city planning and design	2.2 Connection with water	3.2 Equitable access to safe and reliable sanitation	4.2 Low GHG emissions in water sector	5.2 Surface water quality and flows	6.2 Urban elements functioning as part of the urban water system	7.2 Multi-functional water system infrastructure
1.3 Cross-sector institutional arrangements and processes	2.3 Shared ownership, management and responsibility of water assets	3.3 Equitable access to flood protection	4.3 Low end-user potable water demand	5.3 Groundwater quality and replenishment	6.3 Vegetation coverage	7.3 Integration and intelligent control
1.4 Public engagement, participation and transparency	2.4 Community preparedness and response to extreme events	3.4 Equitable and affordable access to amenity values of water-related assets	4.4 Water-related business opportunities	5.4 Protect existing areas of high ecological value		7.4 Robust infrastructures
1.5 Leadership, long-term vision and commitment	2.5 Culture, heritage and first nations involvement in water planning		4.5 Maximised resource recovery			7.5 Infrastructure and ownership at multiple scales
1.6 Water resourcing and funding to deliver broad societal value						7.6 Adequate maintenance
1.7 Equitable representation of perspectives						

16 Formal/Informal
18 City-wide

Figure 28: The ‘Water Sensitive City Index’

The ‘Water Sensitive Cities Index’ benchmarking component was undertaken during a full day workshop on 18 August 2020 with 50 targeted water sector stakeholders (Zutari, 2020b). A

comprehensive systems analysis of Cape Town also contributed to the benchmarking and served to verify information. Figure 29 presents a radar chart showing the mean ratings for the three result sets (formal, informal and overall) in terms of the seven goals of a WSC and the percentage attainment of each city state for the formal, informal and overall/citywide areas. The formal areas had the highest mean goal ratings, followed by overall and then informal.

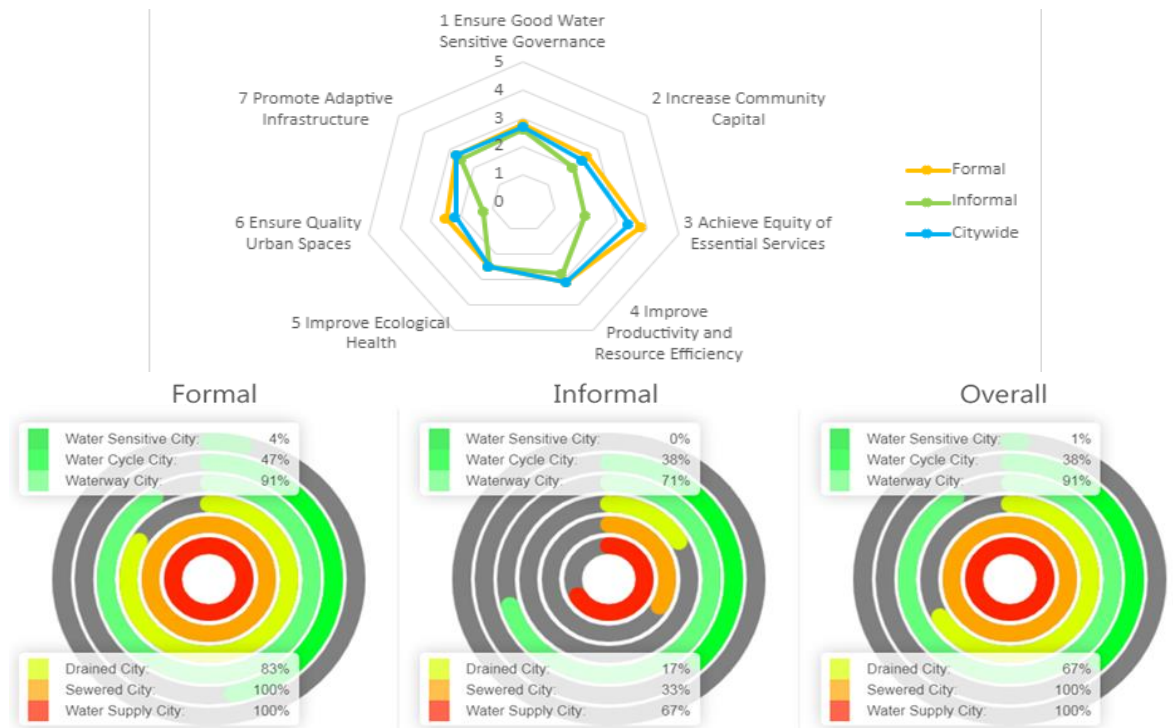


Figure 29: The ‘Water Sensitive City Index’ scores and the city state percentage scores

The formal areas and the CCT overall were deemed to have fully achieved the Water Supply and Sewered City states and were in various stages of transition to the Drained City state. There was some attainment of the Waterway (91%) and Water Cycle (38%) city states. Formal areas rated 83% as a Drained City, with the stormwater drainage system in the CCT functioning effectively on a day-to-day basis and protecting most citizens from flooding. The relatively high rating for the Waterway City was particularly surprising as none of the stakeholders considered the CCT to be close to having healthy waterways. From the project, it was proposed for further research that the Waterway City be reframed as the ‘Water Conscious City’, with significant social awareness around water issues, water efficiency, waste reduction, good water sensitive governance and the promotion of adaptive infrastructure. Formal areas rated 47% as a Water Cycle City. This was largely attributed to Goal 3 ‘Achieve equity of essential services’ and Goal 4 ‘Improve productivity and resource efficiency’. The water crisis, owing in part to the below average rainfall received from 2015 to 2017, led to water-wise behaviours and practices and increased commercial opportunities related to water productivity.

The informal areas had not yet fully achieved any city state. The highest rating was surprisingly for the Waterway City (71%) followed by the Water Supply City (67%), with particularly low ratings for the Drained City (17%) and the Water Cycle City (38%). The CCT is responsible for service provision in informal areas. It has basic water and sanitation service targets of at least one shared toilet to a maximum of five households and one tap to 25 households, within a maximum walking distance of 200 m.

The low rating for the Water Supply City reflects stakeholders' views that communal standpipes located outside of citizen's homes indicate that issues of equity and access are not sufficiently addressed. Despite the CCT's sanitation service level targets, the politics around access to sanitation, rather than simply numbers of toilets, were discussion points. In particular, stakeholders regarded organised crime groups, community hierarchy and politics, and issues of safety (especially at night and for women and children) as the contributing factors. Stakeholders also emphasised the need for new metrics and ways of measuring beyond numbers of toilets. They highlighted the need for an expanded understanding of what access to water and sanitation in informal settlements means for a WSC. Informal areas rated particularly low with a 17% attainment of the Drained City state. Drainage is not considered as a basic service in RSA, unlike water and sanitation. Flooding is a significant problem that disrupts life in informal settlements and poses a risk of severe consequences to life. The more aspirational elements of the last three city states were particularly lacking in informal settlements. There is low vegetation coverage, limited access to blue green spaces and low amenity value.

Numerous lessons emerged from the benchmarking including the need for separate scoring for informal and formal areas and the importance of culture, heritage and first nations indigenous knowledge in water planning (Zutari, 2020a). Moreover, the 'Water Sensitive Cities Index' results illuminated the practical realities and constraints to achieving a WSC, revealing the weaknesses in Cape Town. For example, poor water quality near informal settlements potentially curbs the use of stormwater for MAR or amenity.

Following the benchmarking phase, the second visioning phase consisted of a workshop (Zutari, 2021a). It was held on 28 October 2020 with 30 selected water sector stakeholders. Three activities were undertaken to form a water sensitive vision: (1) a 'Time Travel' exercise to develop the CCT's 'water story', (2) a 'Visioning Headlines' exercise to draw out aspirations for the CCT's water future for the next 50 years, and (3) a 'Visioning Outcomes' exercise to draw out vision themes. After the workshop, the vision was refined through multiple rounds of stakeholder feedback. Figure 30 shows the CCT water sensitive vision, which was underpinned by three critical pillars and abbreviated to H2O. Core components of the vision included resilient infrastructure, equity, basic service provision, good governance, healthy waterways, liveable spaces and climate change resilience.

The third and final phase was transition planning and strategy development (Zutari, 2021b). During this phase two half-day workshops were held on 27 January 2021 and 10 February 2021 with approximately 40 selected water sector stakeholders. The workshops were part of a larger

process of identifying key focus areas for implementation. They involved the application of the CRCWSC's Transitions Dynamic Framework to refine the focus areas. Insights from the workshops and a project team analysis were used to develop focus areas, and prioritising actions for an WSC strategy.

"A world class African city that celebrates providing equitable and dignified access to water services that are underpinned by resilient water sensitive infrastructure."

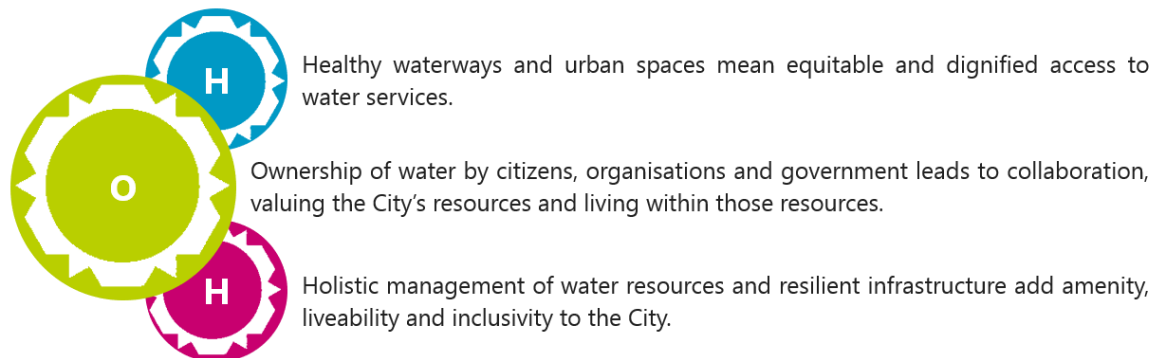


Figure 30: Cape Town's water sensitive vision

The Cape Town WSC Implementation Strategy is shown in Figure 31. It comprised a three-phase approach: (1) 'Phase One: Ensuring that the fundamental aspects of the transition are in place', which included six key priority action areas – Champions and Networks, Terminology versus Jargon, Research and Capacity, Indigenous Knowledge, Governance and Planning, and Integrated Planning (Table 9), (2) 'Phase Two: Applying the lessons learnt from Phase One across the rest of Cape Town', in order to embed water sensitive practices throughout CCT and reviewing the benefits of water sensitive projects, and (3) 'Phase Three: To be developed', based on the outcomes of Phases One and Two but should be focused on the ongoing implementation of WSC practices and international best practice at the time.

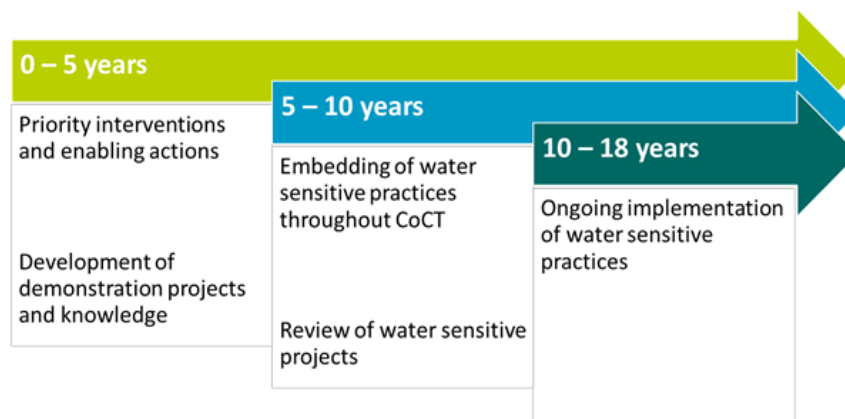


Figure 31: Cape Town's three phase WSC Implementation strategy

Table 9: Summary of WSC Priority actions and sub-actions

	WSC Priority Action	Summary of actions and sub-actions
1	Champions and Networks	The appointment of a water sensitive champion to lead a transversal team to coordinate and support the implementation of water sensitivity in Cape Town.
2	Terminology versus Jargon	CCT officials must ensure that they are explicit and accurate in their application of terminology, and where possible, work towards the consistent use of terminology in the CCT.
3	Research and Capacity	The CCT should consider including ‘Research skills’ or association with relevant research institutions to be included in all term tenders.
		The CCT should ensure any international consultants commit to knowledge transfer to local institutions.
		The CCT should commit to sharing data with stakeholders in the research community increasingly.
		Improve peer-learning among service providers and stakeholders.
4	Indigenous Knowledge	CCT identifies a champion for supporting and developing indigenous knowledge within Cape Town. Including, amongst others, the following: Consolidating relevant information and policies exist relating to indigenous knowledge. Incorporating indigenous knowledge into policy/ a policy. An example of indigenous knowledge that might easily be incorporated into the CCT’S policies is that it could be built into CCT SuDS Landscape and Indigenous Plant Species Guideline. Development of a comprehensive history of the ‘Cape Town Water Story’, building on the work in Brown & Magoba (2009) which focused primarily on drainage and the post-colonial period. Development of a spatial dataset of important sites related to water infrastructure.
5	Governance	Strengthen integrated basin governance and capabilities (i.e., engaging with other stakeholders and water users particularly of the WCWSS). Advance water allocation reform including accurate and up-to-date data. Improve financial sustainability in water and sanitation services.
6	Planning & Integrated Planning	The CCT’s Department of Water and Sanitation should work in a transversal manner to ensure all stakeholders understand their role in planning and how that supports the transition to a WSC by 2040.
		The CCT’s Department of Water and Sanitation, in collaboration with other directorates, should develop a ‘Water Sensitive Spatial Overlay’. This will entail the consolidation, linking too, existing spatial layers, and collecting and analysing additional information.
7	WSC Demonstration Projects	The CCT should implement a number of WSC demonstration projects to assist in developing the working principles and collaboration needed to scale up WSC solutions more widely across the City.

Components of the third phase were:

- ‘Action 4 Indigenous Knowledge’: the project highlighted the value and importance of

indigenous knowledge in water systems. It was, however, clear that this was a ‘new’ concept for all stakeholders – both within and outside of the CCT. To begin incorporating indigenous knowledge, this action proposed the development of a spatial dataset of important sites related to water infrastructure. The importance of indigenous aspects also emphasised the importance of cultural and heritage aspects in water systems.

- ‘Action 6 Planning & Integrated Planning’: the strategy recommended that the CCT’s Department of Water and Sanitation, in collaboration with other directorates, develops a ‘Water Sensitive Spatial Overlay’. This will entail the consolidation and linking of existing spatial layers, and collecting and analysing additional information. The proposed layer/layers would incorporate information on, amongst others, the following: rainwater harvesting (where rainwater harvesting should be enforced, where it should be encouraged, where it offers little benefit); groundwater (recharge zones, abstraction versus protected zones); stormwater (stormwater networks with appropriate environmental buffers), flood inundation layers, wetlands, strategic water source areas; indigenous and cultural assets (areas where indigenous knowledge should be incorporated, areas that require investigation); water supply (zones fed by infrastructure with significant constraints, target water demands per suburb based on historical demands and property size); sanitation and wastewater (zones fed by infrastructure with significant constraints and zones where there is adequate capacity in the infrastructure).
- To plan or not to plan in informal settlements: the high density and dynamic nature of informal settlements makes it challenging to provide the conventional water infrastructure solutions afforded to formal urban areas. Applying WSC principles to formal areas may be preferable to develop an evidence base and experience with the interventions and governance arrangements before attempting to apply it to informal settlements.

4.5 Summary

This chapter discussed the case study context of Cape Town. It described various complex urban challenges facing the city such as degrees of informality and competition for space for housing. These challenges need to be considered during planning for a WSC. Water sensitivity has been increasingly embraced in city policy and planning since 2009 after a long history of conventional and centralised water infrastructure, management and planning approaches. The city provides a suitable case study context to develop an MCA methodology through. This is due, in part, to its 2020 water strategy commitment to ‘*become a Water Sensitive City*’ by 2040, and the initial actions taken to deliver on this through the ‘Benchmarking the city of Cape Town as a Water Sensitive City’ project. The city’s existing BI present options for the MCA that are discussed in the next chapter.

5. Selecting options: existing stormwater ponds in Cape Town

This chapter describes the selection of BI options for the MCA. In an MCA, options provide a focus point to contribute to the achievement of the objectives (Section 2.9). First, the chapter discusses the CCT's existing BI options and the selection of stormwater ponds for this research. The chapter then describes the existing stormwater ponds and details the acquisition and refining of a stormwater ponds dataset.

5.1 Existing blue infrastructure options

This research focuses on planning for BGI as a strategy for a WSC. In urban areas where it is not possible to expand BGI, existing BI can be transformed into BGI to provide multiple benefits. BGI combines blue (water bodies) and green (vegetated areas) infrastructure into an interconnected network that provides multiple functions (O'Donnell *et al.*, 2021).

In the case study context of Cape Town, the city's existing BI, such as stormwater ponds, wetlands and sections of river (Section 4.2), present promising opportunities for options for the MCA. The City's existing stormwater ponds were selected for this study for the following reasons:

- (1) Stormwater ponds provide an existing focus point, occupying physical space with a defined number of features distributed across the city, and with resources already invested in them.
- (2) Stormwater ponds have already been selected for the 'Pathways to water resilient South African cities' project (Section 1.4). It identified them as potential WSC transition pathways. The project has an active demonstration site transforming an engineered single-purpose stormwater pond into a multifunctional space providing enhanced MAR, biodiversity and amenity, and connections with a nearby school in a socio-economically disadvantaged neighbourhood (Figure 32) (Mclachlan *et al.*, 2023).
- (3) The CCT water strategy commitment to '*become a Water Sensitive City*' by 2040 specifically references diversified infrastructure, the optimal use of stormwater and multifunctionality for the purposes of flood control, aquifer recharge and water re-use and recreation with sound ecological principles (City of Cape Town, 2020b). This aligns with multifunctional stormwater ponds.
- (4) The CCT is already engaged with the planning and implementation of multifunctional upgraded stormwater ponds and related stormwater infrastructure and waterway reaches at several sites. This includes through the Philippi Local Spatial Development framework (localised planning scale below district), which focuses on a low-lying flood prone area with degrees of informality. The framework references the problem of stormwater ponds in the area as hotspots for crime and illegal dumping. It has a key focus area of upgrading



Figure 32: The pond being transformed for multifunctionality (Tanyanyiwa *et al.*, 2023)

underutilised storm water retention ponds into a network of integrated multifunctional spaces for sports, recreation and food gardens, and especially for education and youth programmes (City of Cape Town, 2022a). A conceptual proposal for the stormwater pond upgrades has been completed (HHO Consulting Engineers, 2023). The Liveable Urban Waterways Project is another CCT initiative. It has aims related to WSUD, waterway rehabilitation, NBS and GI with a monitoring framework defining a liveable waterway by six elements: (1) liveability including acceptable water quality, (2) makes space for the water, (3) has a functioning ecology, (4) connects the waterway to the water table and the floodplain, (5) connects communities and is enjoyed by communities, and (6) provides a range of ecosystem services, economic and social benefits (Faragher, 2022; Lukhozi Consulting Engineers, 2022). While this project largely focuses on waterways, stormwater ponds are included. More CCT examples include the rehabilitation and conversion of the deteriorated Ithemba Labantu detention pond into a dual sports facility (Figure 33) (City of Cape Town, 2020a) and the upgrading of a highly polluted stormwater channel to improve water quality, liveability and amenity for the surrounding community (City of Cape Town, 2016). Additionally, some of the stormwater ponds in the City already include the functions of a park, sports facility or outdoor gym (Figure 34) (City of Cape Town, n.d.-c, 2019i).



Figure 33: The conversion of the Ithemba Labantu detention pond (CCT, 2021)



Figure 34: A CCT park including an outdoor gym and a stormwater pond

The CCT's mostly monofunctional ponds were primarily designed to serve a flood control function. They fit into the 'Drained City' state on the UWMTF but present a potential missed opportunity to provide multifunctional benefits as BGI towards a WSC (Figure 35). As existing BI options in Cape Town, the MCA can assist with evaluating the potential of the ponds to provide multiple benefits.

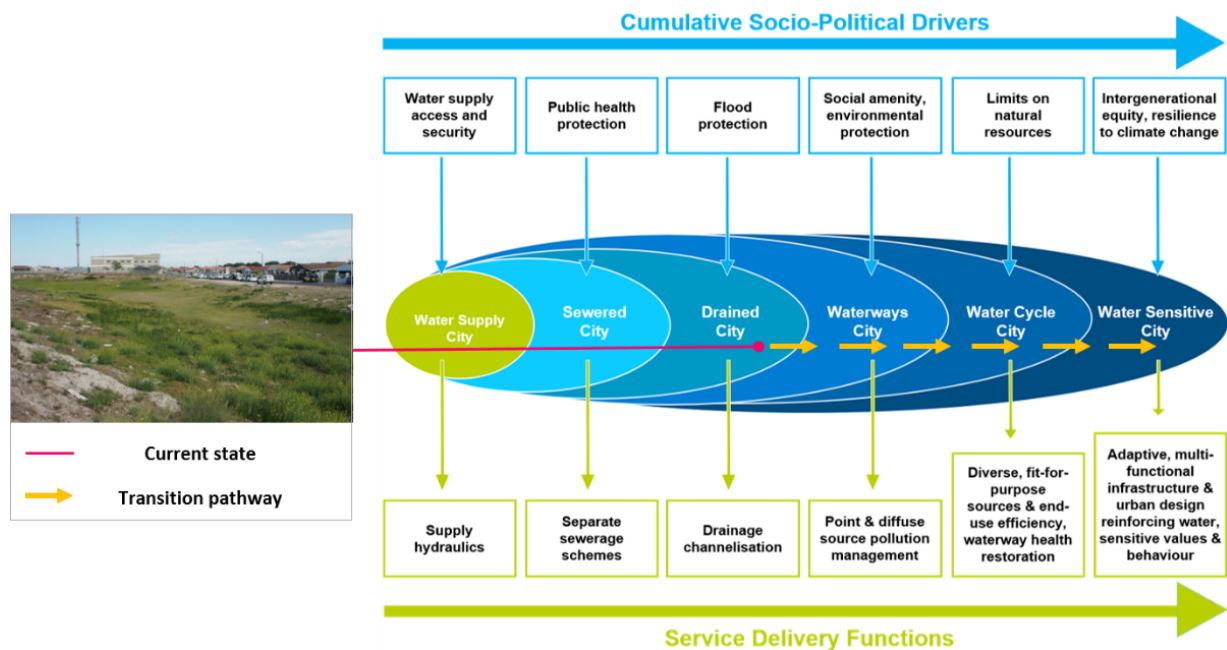


Figure 35: The potential transition pathways for existing stormwater ponds
(adapted from Wong *et al.* (2020))

5.2 Stormwater ponds

Stormwater ponds form part of regional controls for urban drainage systems. They capture, control and filter surface runoff from rainfall events before it is discharged to a receiving water body. Stormwater is defined as rainfall (after initial losses and ongoing infiltration) converted to runoff from predominantly impervious areas (e.g., roads, roofs, footpaths, car parks, etc.), as well as from pervious areas (e.g., gardens, lawns, vegetated open spaces, etc.) during high intensity rainfall events (Hamlyn-Harris *et al.*, 2018; Dandy *et al.*, 2019).

From a stormwater management perspective, stormwater ponds address increased surface runoff from urban surfaces and reduce flooding risks (Butler & Davies, 2011). They can be considered as a part of SuDS, which offer an alternative approach to conventional drainage systems. SuDS manage surface water drainage systems holistically and sustainably, mimicking the natural hydrological cycle. The SuDS hierarchy describes its objectives as the effective management of stormwater runoff quantity and quality and, following that, the provision of amenity and the preservation of biodiversity (Armitage *et al.*, 2013).

Stormwater ponds can be characterised into three main types: detention ponds, retention ponds and wetlands (Armitage *et al.*, 2013). Detention ponds temporarily store runoff for short periods of time, typically for 24 to 72 hours, and are dry otherwise. Their primary purpose is to attenuate the peak flows from large storm events and thereby reduce the downstream flooding risk. Most are grassed or vegetation lined but some are concrete lined. The stormwater either infiltrates into the soil layers or is released to downstream waterbodies at a predetermined rate through a ‘grey’ engineered outlet structure (Marsalek *et al.*, 1993). They are widely used due to their relative ease of operation and maintenance; however, they are dependent on the availability of space. The short residence time means they don’t usually provide a significant water quality improvement benefit, although they can serve other purposes such as car parks or recreational areas.

Retention ponds have a permanent pool of water and provide a water quality improvement benefit alongside flood risk mitigation. The maximum storage capacity of retention ponds is larger than the permanent pool of water which allows for the attenuation of runoff from storm events (Keyvanfar *et al.*, 2021). Processes such as sedimentation, filtration, infiltration and biological uptake assist with the water quality improvement function. Retention ponds usually have a medium to high pollutant removal capacity (Stahre, 2006). Retention ponds require care in the design process and regular maintenance to manage health and safety risks such as drowning, control mosquito breeding and enhance aesthetic appeal. They can provide opportunities for amenity and increased biodiversity, as well as, in some cases, increases in property prices near the pond. There are also opportunities for water re-use of the permanent pool (Armitage *et al.*, 2013).

Wetlands are typically characterised as marshy areas with shallow water and partial or complete coverage of aquatic vegetation. They can be categorised into natural, modified natural or constructed, and provide more of a water quality improvement benefit than flood control

(Department of Planning and Local Government, 2010). Processes that support water quality improvement in wetlands generally include sedimentation, fine particle filtration and biological nutrient and pathogen removal (Parkinson & Mark, 2005). Wetlands can support significant biodiversity and increased ecosystem health. Additionally, they provide an aesthetic appeal that makes them attractive for recreational activities and property ownership alongside them (Gwang *et al.*, 2012).

Stormwater management is typically the primary purpose of stormwater ponds, with ponds usually designed through the consideration of ‘design storms’. In addition to managing stormwater, stormwater ponds can provide a range of other benefits and functions such as MAR, biodiversity, amenity, liveability, UHI reduction and cultural and education services (Butler & Davies, 2011; Armitage *et al.*, 2014; Uzomah *et al.*, 2014, Mclachlan *et al.*, 2023; Tanyanyiwa *et al.*, 2023). Ashley *et al.* (2017) notes that *‘if the added benefits to society that can be provided by using SuDS/GI are to be realised then the ‘drainage’ perspective needs to be supplanted by one in which Blue-Green infrastructure is seen as a starting point for the planning of land use and property development or renovation; i.e., it is no longer ‘drainage’ that we need; rather what can be achieved is too valuable to be so pigeonholed’*.

5.3 Stormwater quality

In Global South contexts such as RSA, poor stormwater quality is generally a concern which has implications for BGI (Fisher-Jeffes, 2015; Okedi, 2019). Stormwater quality is highly variable and dependent on site conditions, land uses, activities in a catchment and climate (e.g., rainfall intensity and antecedent moisture conditions). It is also dependent on the state of infrastructure in a catchment – particularly wastewater infrastructure (Mitchell *et al.*, 2006). Alan Plummer Associates (2010) discuss some general trends pertaining to stormwater quality and land use:

- The presence of industrial land uses and paved roads with high traffic volumes increases the likelihood of chemical pollution of stormwater.
- Stormwater from commercial and industrial catchments generally has lower concentrations of nutrients and higher concentrations of heavy metals than stormwater from residential catchments.
- High volumes/frequencies of sewer overflows increase the likelihood of pathogens in stormwater runoff.
- Stormwater from residential catchments tends to have greater coliform levels by one order of magnitude than stormwater from commercial and industrial catchments, due to the presence of domestic animals.
- Stormwater from totally urbanised catchments is likely to have higher chemical concentrations than stormwater from partially urbanised catchments.

The primary sources of pollutants in urban catchments include vehicle emissions, building and

road erosion, animal faeces, litter, sewage leakages, atmospheric deposition, spills of household cleaners and motor fluids and direct discharges of wastewater (Butler & Davies, 2011). Table 10 lists urban pollutants and their most common sources.

Table 10: Common stormwater contaminants and their sources (Schoeman *et al.*, 2001)

Pollutants	Sources
Nutrients, faecal bacteria, viruses, organic matter.	Domestic wastes, overloaded sanitation systems, night soil dumping, surcharging sewers, absence of sewerage services.
Heavy metals, hydrocarbons, oils, toxins, Nitrogen Oxides, Sulphur dioxide.	Vehicle emissions, industrial emissions, spills, atmospheric deposition, pavements, roads.
Plastics, paper, glass, organic compounds.	Litter, inadequate services, solid waste dumping.
Suspended solids.	Erosion, construction, vegetation removal.
Nitrogen compounds.	Urban pesticides, herbicides and fertilizers.
Phosphorus, Nitrogen and organics.	Vegetation, pollen, atmospheric deposition.

5.4 Obtaining and refining a stormwater ponds dataset in Cape Town

A four-step process was followed to obtain and refine a dataset of the existing stormwater ponds in Cape Town for the MCA (Figure 36).

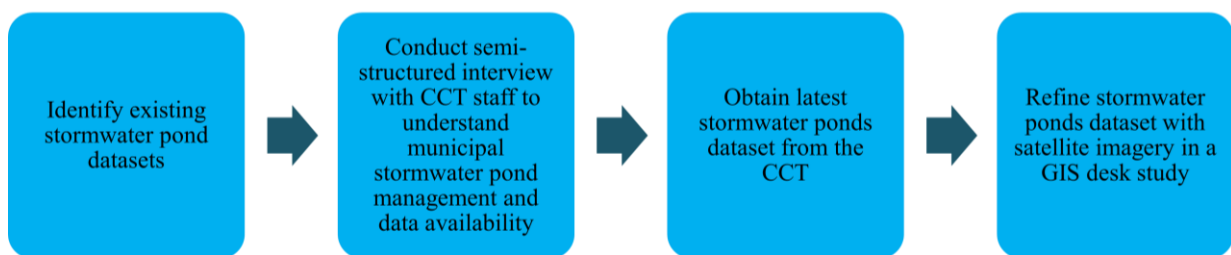


Figure 36: The four-step process of acquiring and refining a stormwater ponds dataset

The process of acquiring an accurate and up-to-date dataset began with the starting point of the CCT's 890 listed existing stormwater ponds in their stormwater infrastructure asset base (City of Cape Town, n.d.-b). Two further available datasets were also identified:

- (1) A dataset developed by Rohrer (2014), with 737 stormwater ponds identified within Cape Town through a GIS analysis of the CCT's existing data and satellite imagery. The study classified 70% of the ponds as detention ponds, 23% as retention ponds and 7% as

wetlands, and established that 68% of stormwater ponds could attenuate a 20-year flood.

- (2) A ‘Stormwater Waterbodies’ dataset from the CCT Open Data Portal described as *‘Stormwater Waterbodies attenuate ground-surface water in natural and artificial wetlands and waterbodies. Stormwater Waterbodies attenuate ground-surface water in natural and artificial wetlands and waterbodies comprised of feature types such as: Dam, Irrigation Pond, Marina, Open Reservoir, Quarry, Stormwater Depression, Stormwater Pond, Waste Water TW Pond, WasteWater TW Effluent Pond and Transformed wetlands’* (City of Cape Town, 2019l). The dataset classifies 535 stormwater ponds and 437 stormwater depressions.

A semi-structured interview was conducted with a CCT staff member in asset management in the Catchment, Stormwater and River Management branch in the Water and Sanitation Department on 4 June 2021 to get a deeper understanding of the stormwater ponds in the city, and clarity on the number of stormwater ponds in an accurate dataset form. The interview provided insights into the stormwater ponds’ purposes, management, ownership, operational aspects and available datasets. A list of the questions and a non-verbatim transcription³ of the responses is provided in Appendix B. Key points from the respondent that were of relevance to the objective of obtaining an accurate stormwater ponds dataset were:

- The accountabilities and roles and responsibilities for stormwater ponds are mixed. The stormwater ponds are owned by either the Catchment, Stormwater and River Management branch or the Roads Infrastructure and Management Department in the Urban Mobility Directorate. The majority of the ponds are likely to be the responsibility of the Roads Infrastructure and Management Department.
- The stormwater ponds asset register is in the form of a CCT GIS stormwater ponds layer because of the spatial representation and the accompanying asset attribute data (e.g., size, catchment, etc.).
- This CCT GIS stormwater ponds layer is the most up-to date and accurate dataset possessed by the City. It is owned and managed primarily by the Roads Infrastructure and Management Department. The department, however, is divided into eight districts and each district is supposed to manage the dataset for their district but not all have a dedicated staff member so some district’s data are more outdated than others. The Catchment, Stormwater and River Management branch also contributes to maintaining the dataset.

The CCT GIS stormwater ponds layer – which serves as the stormwater ponds asset register – was obtained following the semi-structured interview (City of Cape Town, n.d.-d). The dataset

³ A non-verbatim transcription excludes all the unnecessary speech without changing the meaning or structure to make the transcript easier to read and understand (Mirkovich, 2021).

was in the form of a polygon layer with attribute data. A stormwater network dataset (conduits, open water courses, junctions, inlet-outlets, ancillary structures) was also obtained.

The stormwater ponds dataset was then refined through a ground-truthing method to provide a solid foundation for the MCA. The refinement was primarily undertaken by Evans (2021) for an Honours level BSc (Engineering) dissertation co-supervised by the author. The data refinement process centred around the method of ground-truthing, which allows for the validation of data based on field measurements or observation (ESRI, 2021). Due to the large number of ponds within the dataset, ground-truthing validation of the data was carried out using satellite imagery. All assessment of this data was done using QGIS and satellite imagery from Google Maps and Google Earth to check each pond polygon. However, it is noted that there are limitations to such an approach given the city scale. The 1016 listed ponds within the boundary of the city were reduced to 848 ponds through the identification of various issues and anomalies as described in Table 11, with two examples presented in Figures 37 and 38. Appendix C details the deleted ponds.

Table 11: The issues and anomalies and the number of ponds deleted from the dataset

Reason/issue	Description	Number of ponds
Duplicate ponds	Two polygons overlaying each other which identify the same pond.	59
Merged ponds	Ponds that have a shared boundary and represent a single pond.	25
Inner ponds	Ponds located within other ponds boundaries.	34
Informal settlements	Areas that were once ponds but have since been invaded by informal settlements.	7
Anomalies	Ponds with no clear relation to the satellite image or stormwater network.	43
Total Deleted		168



Figure 37: An example of inner ponds



Figure 38: An example of a pond invaded by an informal settlement

5.5 Characteristics of the stormwater ponds dataset

The refined stormwater ponds dataset is visually presented in Figure 39. Over 90% of the stormwater ponds were owned by the municipality as opposed to privately owned, and 80% were detention ponds, 15% were retention ponds and 5% were wetlands (City of Cape Town, n.d.-d). Site visits to sixty-four stormwater ponds were conducted during the research to gain some insight into the functionality and characteristics and place the research in context. These ponds that were visited are listed in Appendix D. A selection of photographs demonstrates some of the variety of ponds in the city and their characteristics (Figures 40 to 49).

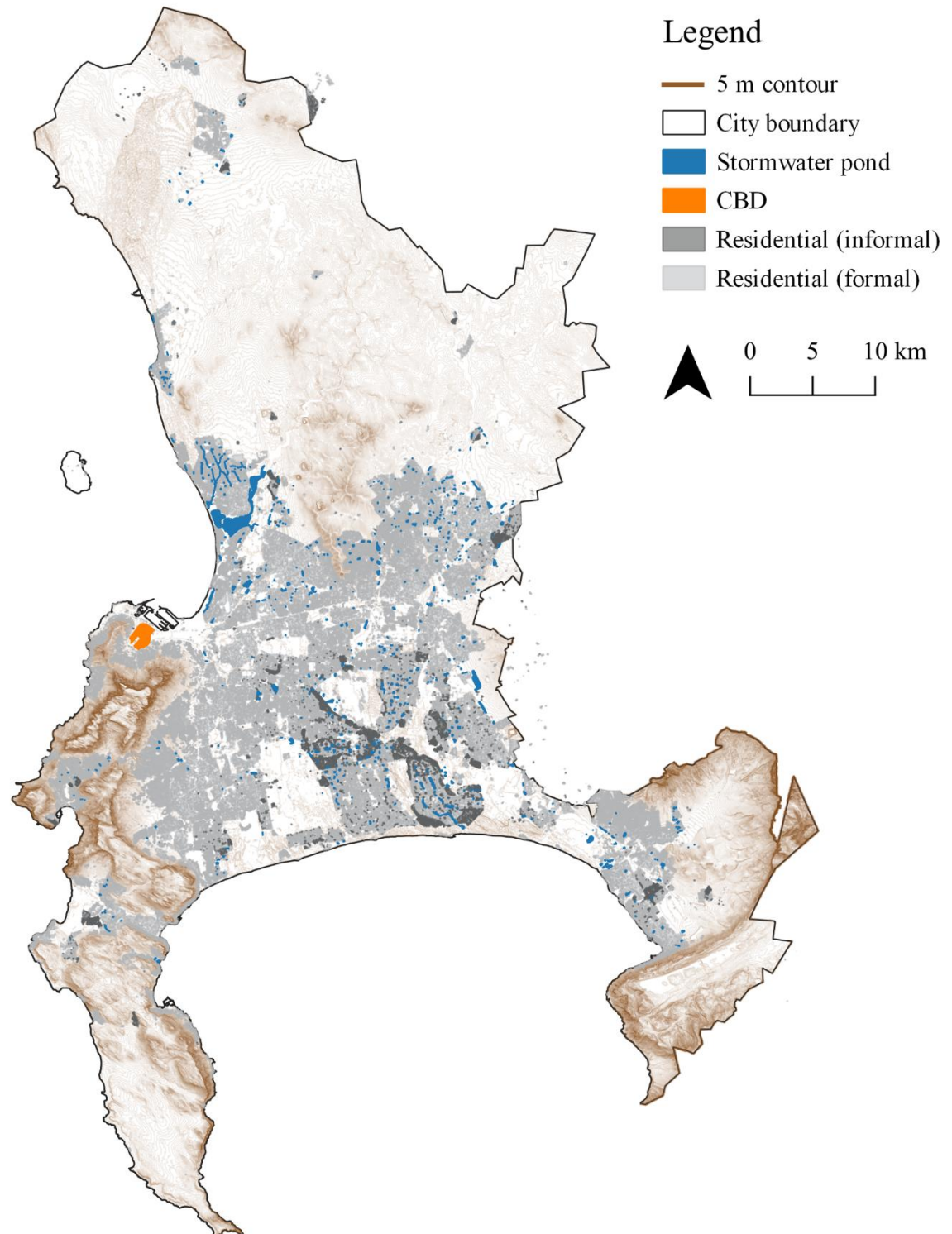


Figure 39: The refined stormwater ponds dataset
 (City of Cape Town, n.d.-d, 2019c, 2019d; Department of Forestry Fisheries and the Environment, 2021)



Figure 40: A sandy detention pond



Figure 41: A grassy and sandy detention pond



Figure 42: A vegetated detention pond along a greenbelt, with the inlet and outlet



Figure 43: Solid waste challenges near a stormwater pond



Figure 44: A vandalised inlet



Figure 45: A retention pond showing an outlet



Figure 46: A vegetated detention pond showing an inlet and scattered litter



Figure 47: A vegetated detention pond showing the inlet and a concrete lined canal through the pond



Figure 48: A detention pond inlet



Figure 49: A retention pond next to a major road showing the outlet

5.6 Summary

The first part of the chapter explored existing BI to serve as options for the MCA, with existing stormwater ponds in Cape Town selected. The second section detailed the four-step process followed to obtain and refine a stormwater ponds dataset for the research. This process resulted in a reduction from 1016 to 848 stormwater ponds and was followed by a description of the stormwater pond characteristics. With the objectives and options selected, the next chapter describes the pilot MCA used to investigate and refine the process.

6. Pilot stormwater pond multi-criteria analysis

This chapter describes the pilot MCA used to investigate and refine the WSC priorities and inform the selection of criteria for the final MCA. Additionally, it was used to facilitate targeted and actionable input from stakeholders. It provided general contributions to the development of the MCA methodology.

6.1 Criteria selection, data acquisition and scoring

The pilot MCA was conducted on Cape Town's stormwater ponds dataset obtained and refined in Section 5.4 (City of Cape Town, n.d.-d). It was based on pre-processed and publicly available datasets, literature and the author's judgement, with no stakeholder input. It used five of the seven WSC planning priorities (objectives) developed in Section 3.4, with an associated criterion selected for each one, based on the proposed criteria in Table 8, data availability and the limited scope of the pilot MCA.

A proportional scoring approach was used as the criteria were quantitatively based. An interval scale of zero (worst performance) to one (best performance) was selected to measure the performance of the ponds against the criteria (Figure 50). Zero was assigned to the worst performing option in the study area (the minimum observed value in the study area), indicating the least potential for the benefit at the ponds and thus the lowest priority for multifunctional stormwater pond transformation if the goal is a WSC with BGI. One was assigned to the best performing option (the maximum observed value in the study area), indicating the highest potential for the benefit. The remaining options were then assigned intermediate scores relative to the zero and one scores and were represented by a linear form. In the case a score fell exactly at a cut-off point, it was assigned to the upper bracket.

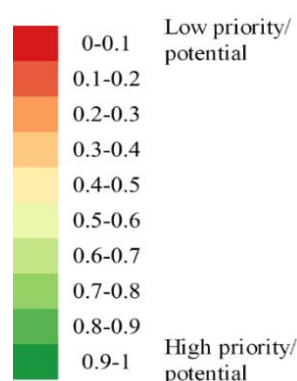


Figure 50: The stormwater pond performance scoring

Microsoft Excel, QGIS and ArcGIS Pro were used for data processing. Spatial queries and associated tools were used to extract criteria data for each pond and create individual criterion

maps⁴ in GIS. The scoring was undertaken in Microsoft Excel. The criterion, and associated selection rationale for each WSC planning priority, as well as the data sources and processing steps are described in Sections 6.2 to 6.6 and summarised in Table 12.

Table 12: Five criteria under the five WSC planning priorities

WSC planning priority	Criterion and data sources	Explanation
Enhancing cultural and heritage associations with water systems	Culture and heritage sites (City of Cape Town, 2019f).	Intersection with Formal National Heritage Resources Act Protection layer indicates potential for the pond to contribute to conserving the heritage resource.
Increasing water re-use	MAR potential (surficial geology, Aquifer type and presence, soil permeability and transmissivity (Bailey & Pitman, 2012; Wright & Jacobs, 2016; Atkins <i>et al.</i> , 2021; World Agroforestry Centre Landscape Portal, 2021)).	Suitable conditions for MAR via surface infiltration are required.
Increasing access to blue-green space	Mean population density within 500 m of pond (Statistics South Africa, 2011).	The higher the population density, the higher the level of potential recreational use by people living in close proximity.
Incorporating stormwater quality limitations	Proximity to informal settlement (Department of Forestry Fisheries and the Environment, 2021).	The further away from an informal settlement, the lower the likelihood for poor stormwater quality impacts to limit other potential functionalities.
Enhancing biodiversity	Terrestrial Biodiversity Network category (City of Cape Town, 2019n).	Significance of the area for conserving biodiversity and maintaining ecosystem functioning according to the Bionet policy categories.

6.2 Enhancing cultural and heritage associations with water systems

The ‘culture and heritage sites’ criterion was constructed using the pond locations and the CCT Local Heritage Resources: Grade III locations, which designates Grade III heritage resources in terms of the National Heritage Resources Act. These are local significance heritage resources worthy of conservation, and include heritage resources designated in the Declared Heritage Protection overlay (City of Cape Town, 2019h). The ponds were assigned as present (i.e., the ponds intersected with the culture and heritage sites) or absent (i.e., the ponds did not intersect

⁴ The maps showing the spatial distribution of the scores for the pilot MCA in Section 6.2 to 6.7 used the pond centroids to represent the ponds

with the culture and heritage sites) from the layer using the ‘Join attributes by location’ tool with the ‘intersects’ geometric predicate. Performance scoring was undertaken on the categories with ‘absent’ scoring zero and ‘present’ scoring one, with 14.3% of the ponds in the ‘present’ category.

Figure 51 presents the scoring of the ponds and their spatial distribution in the study area. Green ponds are those present in the CCT Local Heritage Resources layer, and would be higher priority or offer more potential for the function of enhancing cultural and heritage associations with water systems.

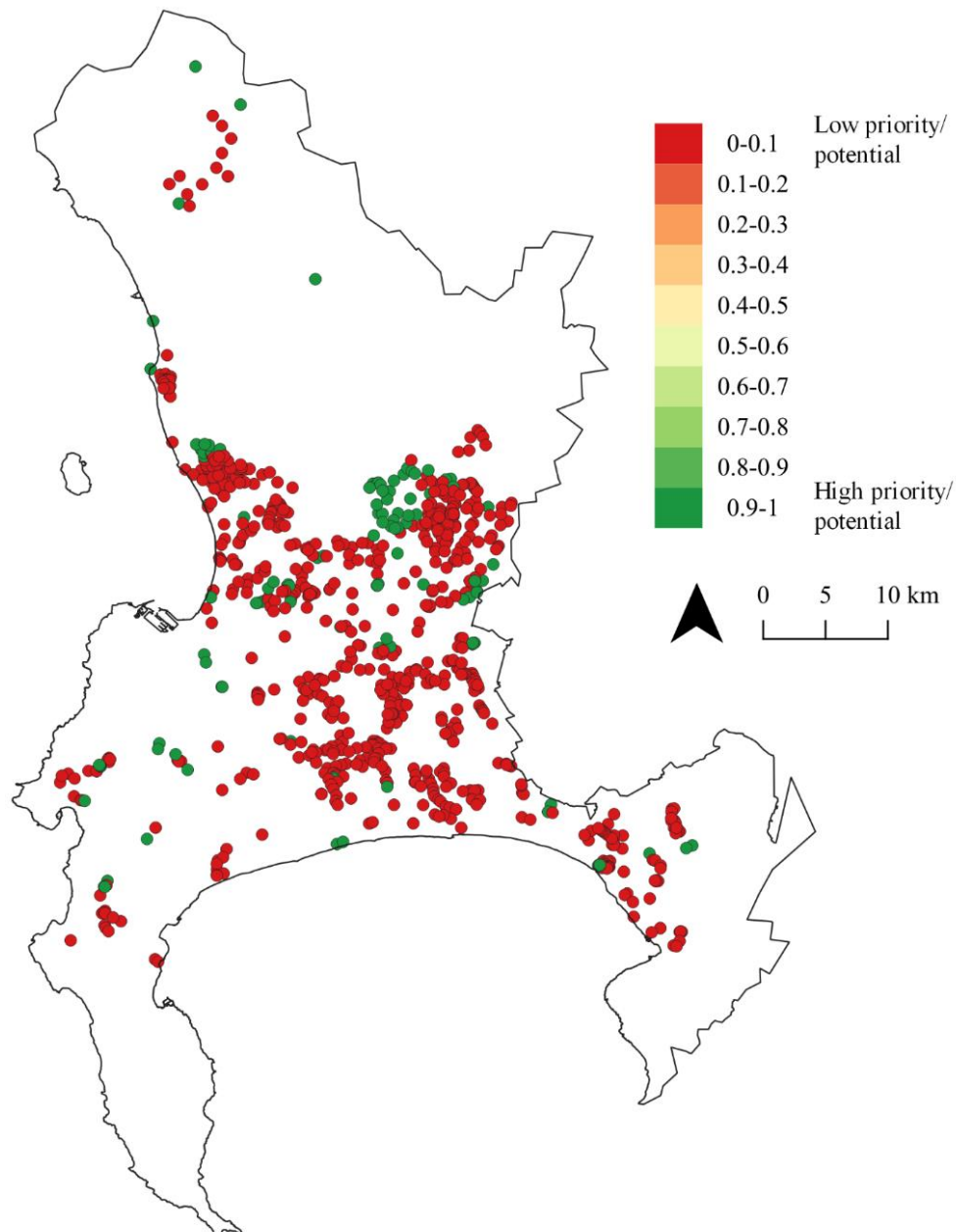


Figure 51: The spatial distribution of the ‘Culture and heritage sites’ criterion scores for the pilot MCA

6.3 Increasing water re-use

The ‘MAR potential’ criterion incorporated four indicators outlined in Table 13 and developed by Evans (2021) for an Honours level BSc (Engineering) dissertation designed and co-supervised by the author primarily using pre-processed datasets that were quantitative in nature.

Table 13: The four indicators for the ‘MAR potential’ criterion for the pilot MCA

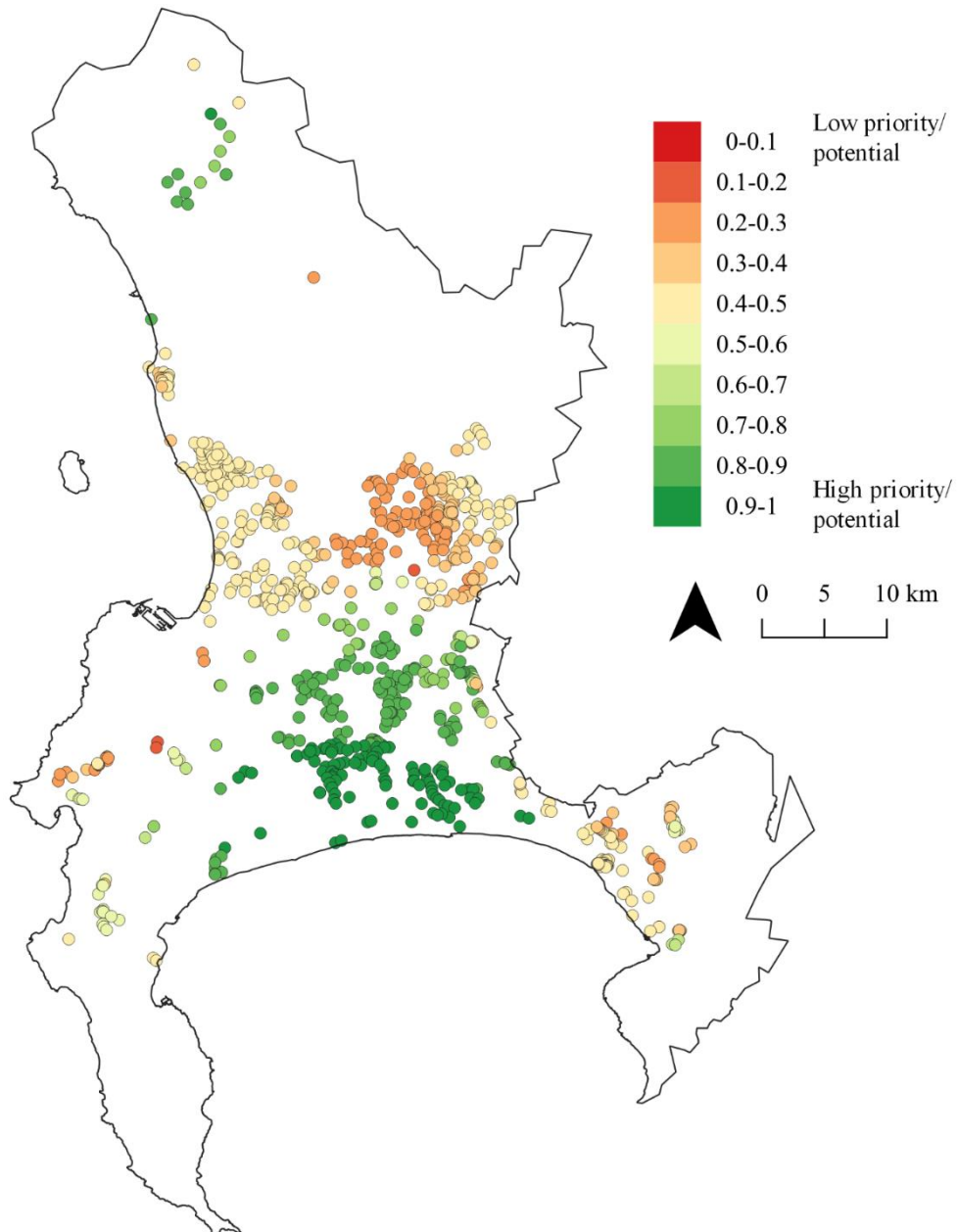
MAR potential indicators and datasets	Description and considerations
Surficial geology (Bailey & Pitman, 2012; Wright & Jacobs, 2016)	Refers to the geological strata directly below the ground surface. This indicator focused on the ability of the surficial geology to allow water to infiltrate to the aquifer below.
Aquifer (Atkins <i>et al.</i> , 2021)	A primary sand aquifer was the favourable requirement for MAR via surface infiltration methods for the study area. For MAR to be most effective, the ponds should be located directly above a primary sand aquifer.
Soil permeability (United States Department of Agriculture, 2007; World Agroforestry Centre Landscape Portal, 2021)	Soil permeability is the ease at which liquids or gases can pass through a layer of soil (Sparks, 2003). The soil below an infiltration pond will be favourable if it composed of gravel, sand, silt or loam to improve permeability. Soil composed of clay is deemed to be impermeable and is unfavourable for MAR via infiltration (Dupont, 2018).
Aquifer transmissivity (Bailey & Pitman, 2012)	Related to the flow of water within an aquifer under a hydraulic gradient. The product of the hydraulic conductivity and thickness of an aquifer (Şen, 2014; Vallero, 2010).

The four indicators were constructed using the pond locations and their associated datasets (Table 13). The ponds were assigned scores for each indicator using the ‘Join attributes by location’ tool with the ‘intersects’ geometric predicate. The scores for each indicator were weighted and combined using Equation 1 from the weighted additive model to produce the ‘MAR potential’ criterion, with the scores from zero to one divided into five MAR potential categories (Table 14). Appendix E provides further detail on this process.

Table 14 and Figure 52 present the scoring of the ponds and their spatial distribution in the study area. Darker green ponds (with higher criterion scores) are those with the most suitable conditions related to surficial geology, aquifer type and presence, soil permeability and transmissivity. They would be higher priority or offer more potential if the goal is to increase water re-use through MAR.

Table 14: The ‘MAR potential’ criterion scores for the pilot MCA

MAR potential	Performance scale	Pond percentage
MAR potential low	0–0.2	0.4%
MAR potential low-medium	0.2–0.4	25.1%
MAR potential moderate	0.4–0.6	38.8%
MAR potential moderate-high	0.6–0.8	6.5%
MAR potential high	0.8–1	29.2%

**Figure 52: The spatial distribution of the ‘MAR potential’ criterion scores for the pilot MCA**

6.4 Increasing access to blue-green space

The ‘Mean population density within 500 m of pond’ criterion was developed by using the 2011 census data (Statistics South Africa, 2011) and calculating and assigning each pond the mean population density within its 500 m radius, using the ‘Join Attributes by Location (Summary)’ tool. This was used to indicate the level of potential use of the pond by people living in close proximity to it. Linear scoring was applied to the population densities, with the largest population density being assigned a value of one to indicate the highest recreation potential.

Table 15 and Figure 53 present the scoring of the ponds and their spatial distribution in the study area. Darker green ponds (with higher criterion scores) are those with higher population densities within a 500 m radius. They would be higher priority or offer more potential if the goal is to increase access to blue-green spaces for recreation.

Table 15: The ‘Mean population density within 500 m of pond’ criterion scores for the pilot MCA

Mean population density within 500 m of pond	Performance scale (mean)	Pond percentage
<1	0	4,8%
1–26	0.1	42,9%
26–51	0.2	25,8%
51–76	0.3	6,3%
76–101	0.4	8,0%
101–126	0.5	4,1%
126–151	0.6	3,2%
151–176	0.7	1,8%
176–201	0.8	1,5%
201–226	0.9	0,9%
>226	1	0,6%

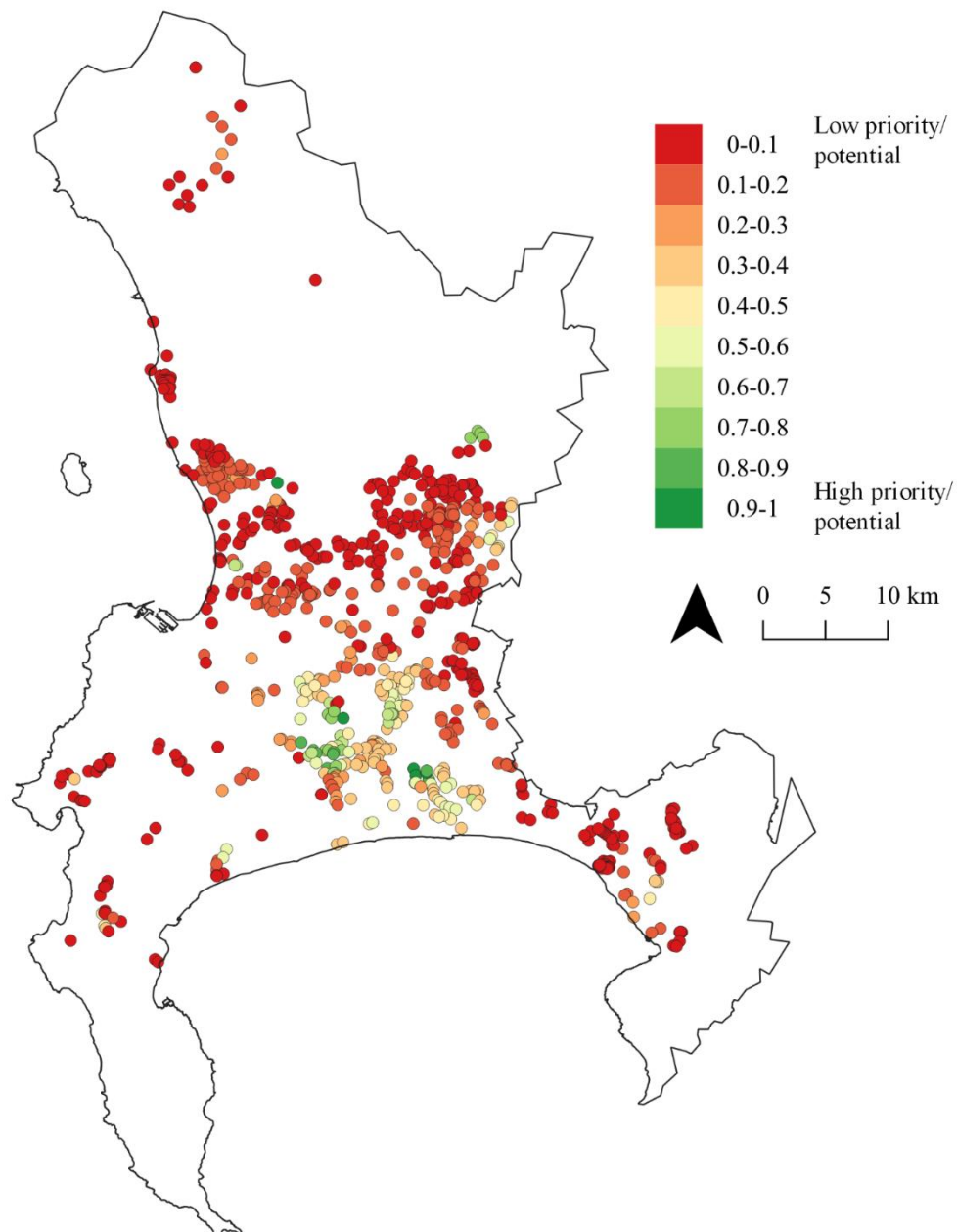


Figure 53: The ‘Mean population density within 500 m of pond’ criterion scores for the pilot MCA

6.5 Incorporating stormwater quality limitations

The ‘Proximity to informal settlement’ criterion was constructed using the pond locations dataset and informal settlement land cover from the South African National Land Cover 2020 dataset (Department of Forestry Fisheries and the Environment, 2021). The Euclidean distance from the ponds to the nearest informal settlement was calculated using the Nearest Neighbour Join (NNJoin) Plugin.

Linear scoring was applied to the distances, with a value of one (best case scenario) assigned to the pond with the longest distance to an informal settlement as it is relatively less likely to be impacted by poor stormwater quality. Thus, it is relatively less likely to have poor stormwater quality impacts on potential functionalities such as MAR, biodiversity and amenity.

Table 16 and Figure 54 present the scoring of the ponds and their spatial distribution in the study area. Darker green ponds (with higher criterion scores) are those with relatively longer distances to an informal settlement – which indicate more potential for multifunctionality (MAR, biodiversity and amenity) as they would be less constrained by stormwater quality impacts.

Table 16: The ‘Proximity to informal settlement’ criterion scores for the pilot MCA

Distance to informal settlement (m)	Performance scale (mean)	Pond %
0–10	0	12,6%
10–50	0.1	2,6%
50–100	0.2	3,7%
100–500	0.3	17,5%
500–1000	0.5	15,4%
1000–2000	0.6	25,1%
2000–3000	0.7	15,3%
3000–4000	0.8	6,6%
4000–5000	0.9	1,1%
>5000	1	0,1%

6.6 Enhancing biodiversity

The ‘Terrestrial Biodiversity Network category’ criterion was based on Cape Town’s Biodiversity Network, a policy instrument as described in the CCT’s Cape Town Bioregional Plan Policy (BioNet) (City of Cape Town, 2015). The BioNet is a spatial plan showing terrestrial and aquatic features that are critical for conserving biodiversity and maintaining ecosystem functioning referred to as Critical Biodiversity Areas (CBAs) and Ecological Support Areas (ESAs) respectively. It contains a map of biodiversity priorities with associated land use planning and decision making guidelines, and management measures. It is designed to inform and guide planning, environmental assessment and natural resource management for all matters concerning biodiversity. The plan adheres to the principles outlined in the National Environmental Management: Biodiversity Act (Republic of South Africa, 2004). The CBAs are required to meet national biodiversity targets for terrestrial and wetland ecosystems according to the National Spatial Biodiversity Assessment. The plan classifies important biodiversity related features and sites, as identified from a fine-scale systematic biodiversity planning analysis in the policy, under various categories and sub-categories (Table 17).

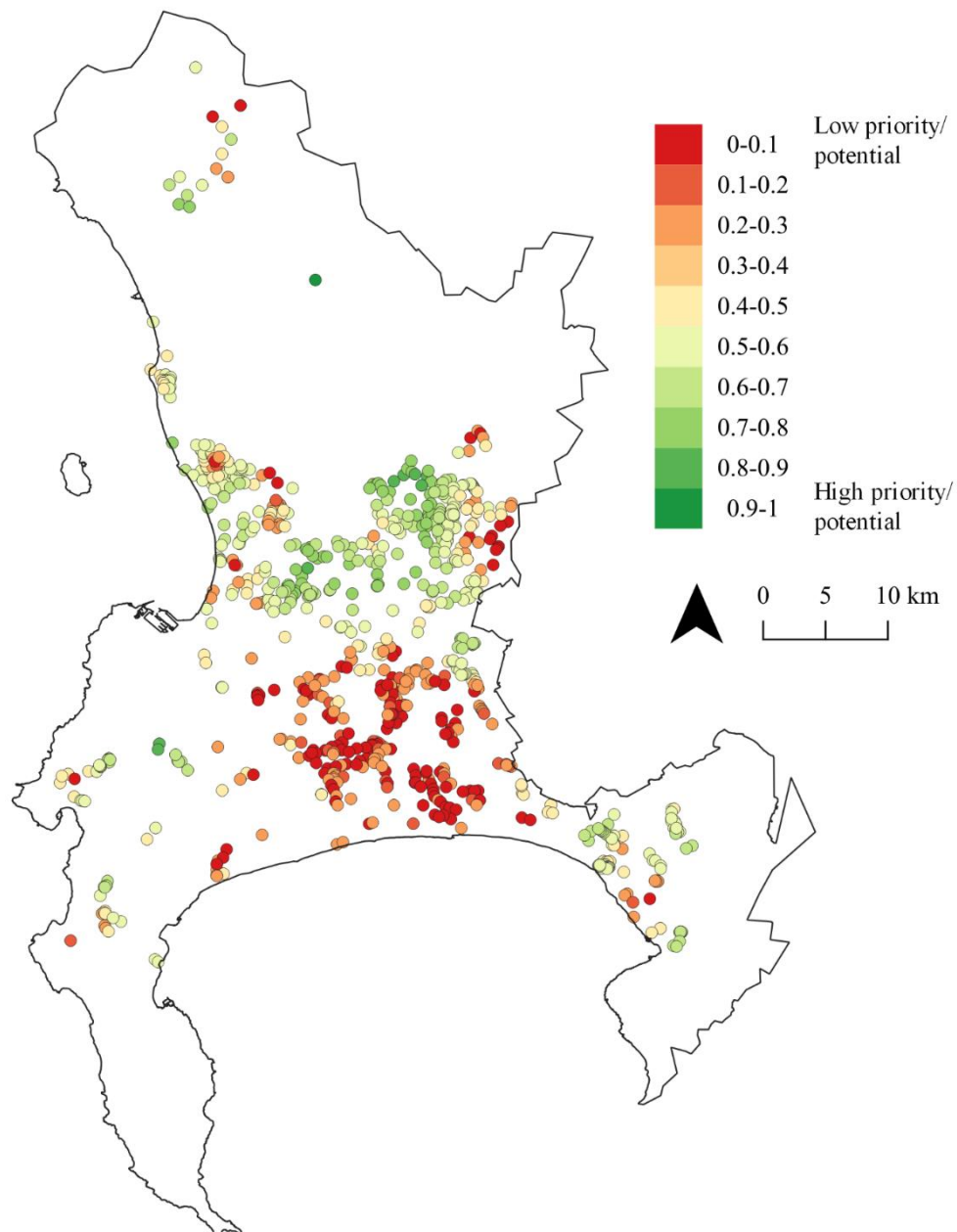


Figure 54: The ‘Proximity to informal settlement’ criterion scores for the pilot MCA

This criterion was constructed with the pond locations dataset and the BioNet category using the ‘Join attributes by location’ tool with the ‘intersects’ geometric predicate (City of Cape Town, 2019n). If the ponds intersected with the BioNet, they were assigned their corresponding BioNet category or if they did not intersect the BioNet they were assigned as ‘absent’. The scoring was based on the BioNet categories which state the relative importance of the different categories (Table 17). Ponds assigned as ‘absent’ were scored zero.

Figure 55 and Table 18 present the scoring of the ponds and their spatial distribution in the study area. Darker green ponds (with higher criterion scores) are those in a relatively more

important BioNet category, and would be higher priority or offer more potential if the goal is to enhance biodiversity. They would be higher priority for transforming and could be done in a way that enhances biodiversity.

Table 17: The BioNet categories and descriptions for the pilot MCA

Category	Description
Protected Areas (Protected: In Perpetuity, Protected: Not In Perpetuity, Conservation Area)	Declared in terms of the National Environmental Management: Protected Areas Act. Forms part of the National Protected Area estate for the country and are listed in the National Protected Areas Register and includes privately-owned contract nature reserves.
CBA 1a	Irreplaceable Core Flora Sites.
CBA 1b	Irreplaceable high and medium condition sites.
CBA 1c	Minimum Set: High and medium condition sites.
CBA 1d	Irreplaceable consolidation sites.
CBA 1e	Connectivity Sites.
CBA 2	Critically Endangered vegetation and associated rivers and wetlands of restorable condition. Required to meet national biodiversity targets, but not for management consolidation, connectivity or viability of critical BioNet sites.
CESA (Critical Ecological Support Areas)	Non-transformed sites of conservation significance and associated rivers and wetlands, required for additional consolidation and ecological support). Essential for management consolidation, connectivity and viability of biodiversity elements in CBA 1a, CBA 1b and protected sites.
OESA (Other Ecological Support Areas)	Transformed (e.g., Extensive Agriculture) sites and associated wetlands, with conservation importance. Important for management consolidation, connectivity and viability of biodiversity elements in CBA1, CBA 2 and protected sites. These sites can contain other natural areas (mostly degraded) located in an extensive or intensive agricultural matrix as the dominant land use.
Other natural areas	Vegetation in good or poor condition that has not been selected as national biodiversity targets are met elsewhere in the BioNet.
No natural habitat	Unselected Transformed sites with little or no conservation value, including areas transformed by human activities, including urban and rural development, cultivated land and mines.

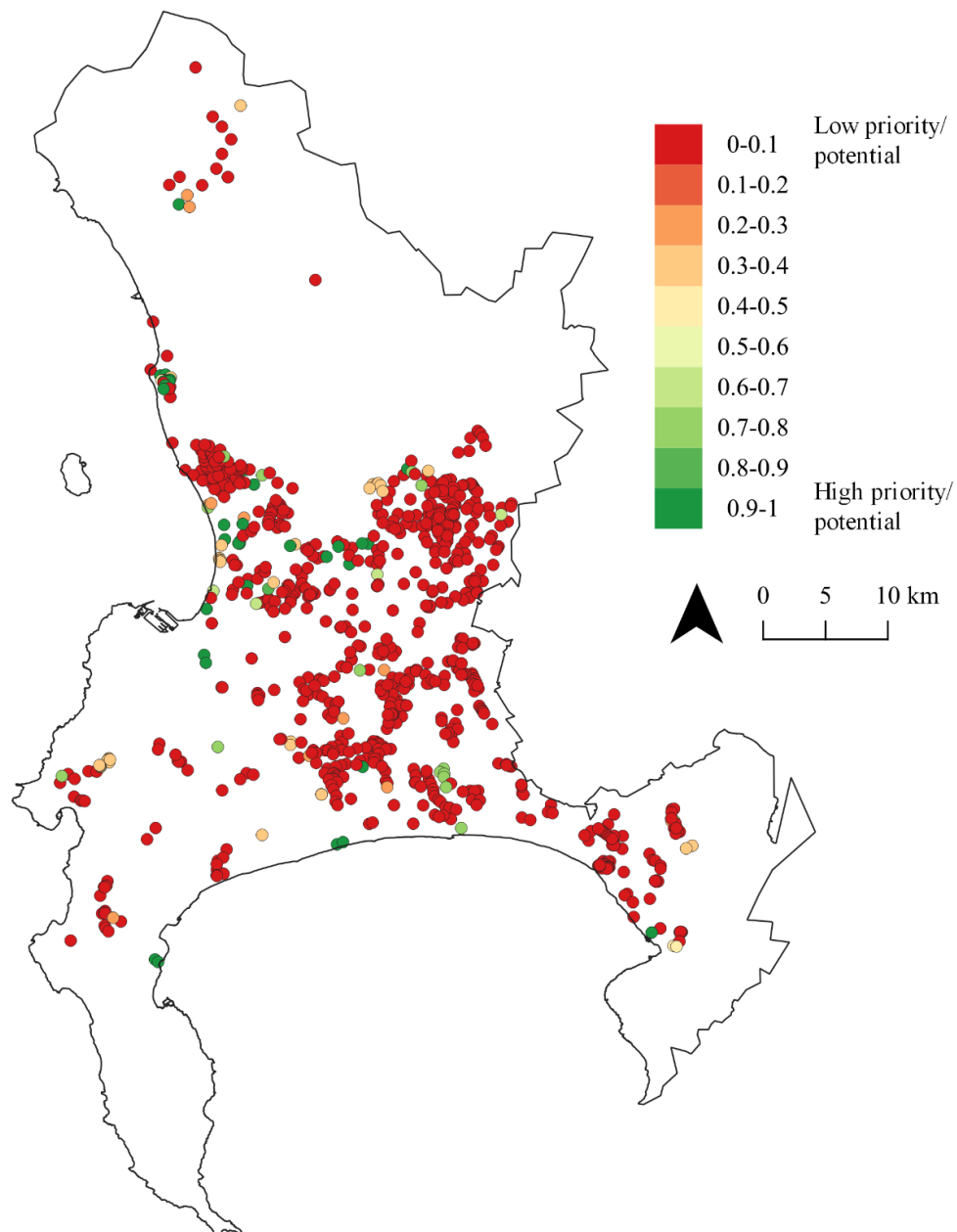


Figure 55: The spatial distribution of the ‘BioNet category’ criterion scores for the pilot MCA

6.7 Combining scores and weights

The five criteria were weighted using the point allocation method, a simple method where 100 points were allocated across the criteria (ODU, 2019). Table 19 shows the weighting of each of the five criteria. As the MCA described in this chapter was a pilot, the weighting was assigned using the authors judgements on the relative importance of each criterion in a WSC and the validity of the data.

The scores from the five criteria and the weights were combined using Equation 1 from the weighted additive model – producing a set of stormwater pond multifunctional potential rankings. Figure 56 and Table 20 shows the scoring of the ponds and their spatial distribution in the study area. These scores show the potential of the ponds to provide a combination of the five benefits, revealing the potential for multifunctional transformation according to the pilot MCA. The highest potential ponds were in the 0.7–0.8 category, with the pond presence percentage of 0.4%, with the row highlighted in green in Table 20.

Table 18: The BioNet category criterion scores for the pilot MCA

BioNet category	Performance scale	Pond percentage
Absent from BioNet	0	87,50%
Other natural areas	0.3	1,30%
OESA	0.4	3,66%
ESA	0.5	0,59%
CBA 2	0.7	0,71%
CBA 1e	0.725	0,12%
CBA 1d	0.75	0,12%
CBA 1c	0.775	0,12%
CBA 1b	0.8	1,53%
CBA 1a	0.9	0,12%
Conservation area	0.95	2,48%
Protected: In Perpetuity	1	1,77%

Table 19: The criteria weightings for the pilot MCA

Criterion	Weighting
Culture and heritage sites	5
MAR potential	30
Mean population density within 500 m of pond	15
Proximity to informal settlement	20
Terrestrial Biodiversity Network category	30

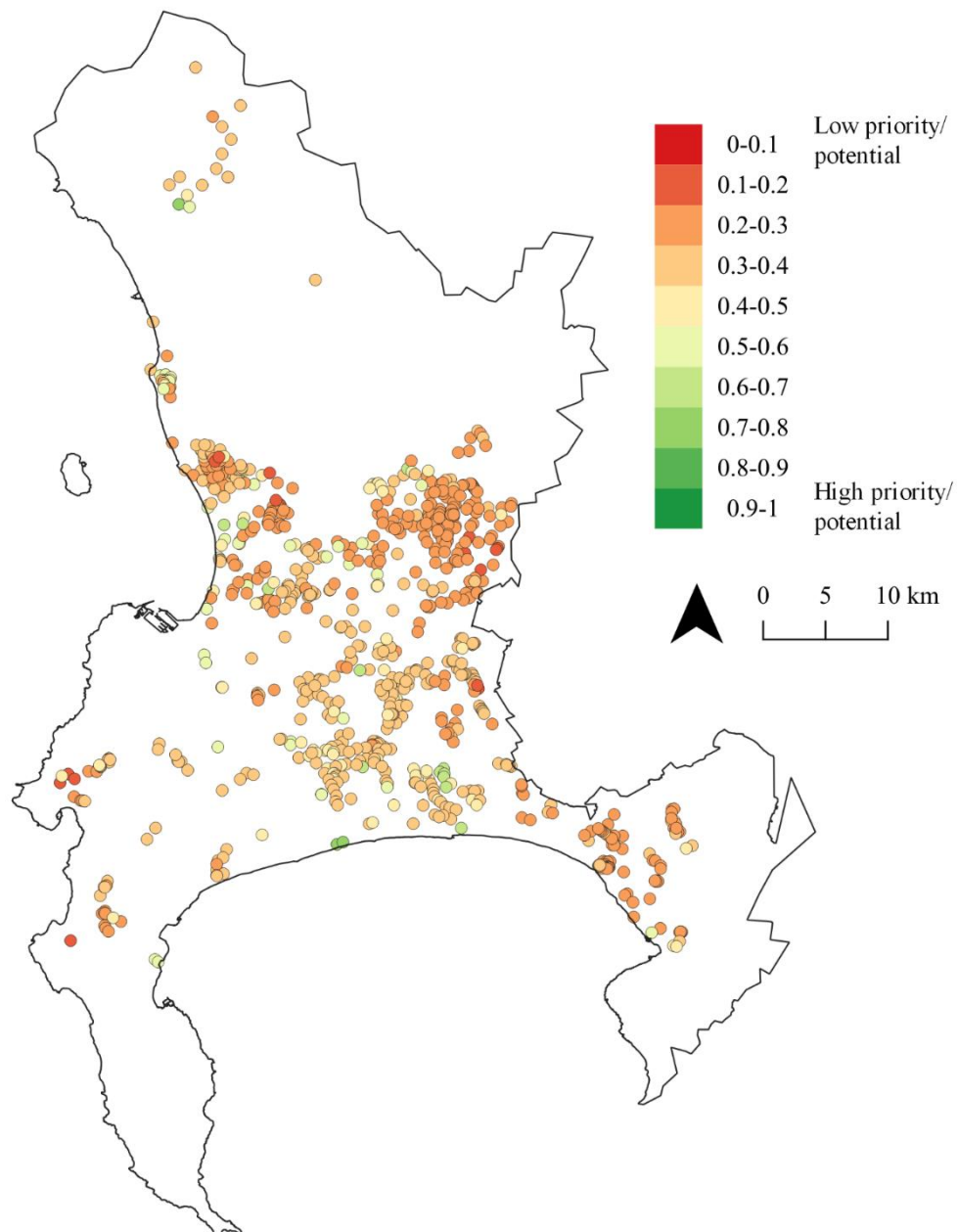


Figure 56: The combined stormwater pond scores for the pilot MCA

6.8 Summary

This chapter presented a pilot MCA with five WSC planning priorities and associated criteria. It was undertaken to investigate and refine the WSC planning priorities and assist with criteria selection for the final MCA. Furthermore, it produced a tangible example of the MCA to facilitate targeted and actionable input from stakeholders. With the objectives and options selected in Section 3.4 and Chapter 5 respectively, and the pilot MCA undertaken in this chapter, stakeholder input was now collected through semi-structured interviews for a collaborative and participatory MCA approach and described in Chapter 7.

Table 20: The distribution of the combined stormwater pond scores for the pilot MCA

Score	Priority/potential	Pond percentage
0–0.1	Low	0%
0.1–0.2		1.9%
0.2–0.3		41.9%
0.3–0.4		40.6%
0.4–0.5	Moderate	9.1%
0.5–0.6	Moderate	4.7%
0.6–0.7		1.5%
0.7–0.8		0.4%
0.8–0.9		0%
0.9–1	High	0%

7. Semi-structured interviews

This chapter describes the seven semi-structured interviews that were conducted to obtain stakeholder input to assist with the refining of the WSC planning priorities and selecting relevant contextual criteria and datasets for the final MCA. Additionally, they provided input on the stormwater ponds as options, criteria scoring and the general MCA methodology.

7.1 Stakeholder selection and question development

Seven professionals engaged in work on WSCs, BGI, GI and resilience at a strategic city-wide level in Cape Town were selected for interview. They were selected with help from the ‘Pathways to water resilient South African cities’ project team (Section 1.4) for their expertise on the seven WSC planning priorities in the hopes that they would be able to provide input on the priorities and criteria. All had knowledge of and were involved in aspects of urban water management, stormwater engineering, urban design, environmental management, groundwater, climate change and resilience. Most (five) of the respondents were from the City of Cape Town Metropolitan Municipality, largely because water services projects at a strategic city-wide level are the constitutional responsibility of the municipalities in RSA. The other two respondents included a consultant at a groundwater consultancy and an academic who conducts WSC research. A WSC transition is still in the early stages in RSA and hence the availability of people that could meaningfully contribute to the MCA was relatively small (Mguni *et al.*, 2022). Table 21 shows the selected stakeholders, their roles and affiliation and their interview date, while Table 22 indicates their expertise across the seven WSC planning priorities.

Table 21: The selected stakeholders, their roles and affiliation and interview date

Stakeholder	Affiliation	Interview date
1	Catchment Stormwater and River Management branch, Water and Sanitation Directorate, CCT.	17 March 2022
2	Urban Sustainability Unit, Urban Planning and Design Department, Spatial Planning and Environment Directorate, CCT.	22 March 2022
3	Decision Support Systems & Data Management, Bulk Water Branch, Water and Sanitation Directorate, CCT.	23 March 2022
4	Consultant, groundwater consultancy.	24 March 2022
5	Future Planning and Resilience, CCT.	1 April 2022
6	Environmental Planning and Sustainability branch, Environmental Management Department, Spatial Planning and Environment Directorate, CCT.	12 April 2022
7	Academic, Department of Civil Engineering, University of Cape Town.	19 April 2022

Table 22: The selected stakeholders' expertise across the WSC planning priorities

WSC planning priority	Stakeholder						
	1	2	3	4	5	6	7
Enhancing cultural and heritage associations with water systems		x			x	x	x
Increasing water re-use			x	x	x		
Reducing climate change impacts		x	x	x	x	x	
Utilising education services potential		x		x	x	x	x
Increasing access to blue-green space	x	x	x	x	x	x	x
Incorporating stormwater quality limitations	x	x	x	x	x	x	x
Enhancing biodiversity	x	x		x	x	x	

The interviews were semi-structured, allowing respondents to talk around a set of open-ended questions. The questions were designed to elicit understanding of their perspectives on WSCs, multifunctionality as a concept, BGI, and stormwater ponds as multifunctional BGI. They were also designed to obtain specific input on the WSC planning priorities, potential criteria, available datasets and scoring.

The questions were split into two broad sections. The first section comprised more general questions relating to multifunctionality, WSC transitions, BGI and stormwater ponds. The questions in the second section were more pointed around the refinement of the WSC planning priorities, the selection of relevant contextual criteria and ascertaining any available datasets. Some of the questions sort specifics, such as 'for biodiversity, is habitat size or enhancing landscape connectivity more important?', while others were more open ended such as 'what activities pose a risk to stormwater quality?'.

The questions in the second section used examples from the proposed criteria from the literature in Table 8. They also used the pilot MCA (Chapter 6). This was aided by a slideshow that was provided to stakeholders before the interview, to illustrate the idea behind the MCA and the criteria. Targeted and actionable input from stakeholders was facilitated through providing tangible examples from the pilot MCA.

Table 23 presents the prompts and types of questions asked. The questions changed in small ways as the interviews continued in response to new framings of the research from the previous respondents. Not every question was asked to each respondent but rather those pertaining to their expertise (Table 22).

Table 23a: The types of questions asked during the semi-structured interviews

Category	Questions
General – WSC transitions, BGI, multifunctionality, and stormwater ponds	• Multifunctionality as a concept is used a lot and emerged as a strategy to make cities water sensitive, liveable, equitable but it is quite visionary – do you think it has value for Cape Town and is it relevant given the basic service delivery and operational challenges the city faces? • The research is looking at stormwater ponds specifically for multifunctionality; do you think stormwater ponds can be transformed into multifunctional spaces? Can they provide benefits beyond flood control? Are there better ways or infrastructure types with which to do this with?
Enhancing cultural and heritage associations with water systems	• For enhancing cultural and heritage associations with water systems, the research looked for presence of the ponds in the heritage resources sites from the heritage auditing layer. Any comments? Any other datasets that could be used to see where ponds are near heritage sites?
Increasing water re-use*	• For MAR potential the research has considered four indicators of aquifer type and presence, transmissivity, soil type and surficial geology. Any other indicators or comments?
Reducing climate change impacts	• For reducing climate change impacts, is UHI reduction or carbon sequestration a higher priority? • Do retention versus detention ponds impact this criterion? • Are there any available datasets for this criterion?
Utilising education services potential	• This planning priority considers education services potential, the potential for learners to use the pond as a space for education by a nearby school. • For this criterion, the research is proposing considering proximity to schools. Do you have any comments or other groups or institutions to include?
Increasing access to blue-green space	• Increasing access to blue-green spaces is about using ponds for amenity purposes. In the example, the research has looked at recreation potential to indicate a higher level of potential use of the pond as recreation space by people as they live in close proximity to it. • In terms of what to measure, which of the following would you prioritise: ponds in areas where people lack access to green space or ponds where people live in close proximity to the space so could use it? Or both? • In terms of access to ponds for amenity – is walking distance or public transport routes more important for accessing a pond? • Regarding security concerns, from a practical perspective should ponds near crime hotspots not be prioritised for amenity as there is more risk and thus people are less likely to use them for amenity? Any other comments? • How do retention versus detention ponds impact recreation potential? • Does pond size have an impact on recreation potential?

Table 23b: The types of questions asked during the semi-structured interviews

Category	Questions
Incorporating stormwater quality limitations	• The next priority is managing stormwater quality, so how can stormwater quality concerns that would limit other functions like amenity and MAR be considered? • In the example, the research has looked at the land cover type in the form of distance to informal settlements; darker green ponds (with higher criterion scores) are those with relatively longer distances to informal settlements – which indicate more potential for multifunctionality (MAR, biodiversity and amenity) as they would be less constrained by stormwater quality impacts. • The research is considering other potentially polluting land covers such as WWTWs, what others would you include?
Enhancing biodiversity	• Can stormwater ponds enhance biodiversity in the city? Any relevant datasets? • For biodiversity, is habitat size or using ponds to enhance landscape connectivity more important? • How do retention versus detention ponds impact on biodiversity? • Does the pond size impact which ponds should be prioritised?
*the questions in this section were considerably more detailed for the groundwater consultant.	

7.2 Interview process

The interviews occurred over the period of 17 March 2022 to 19 April 2022, with the interview dates indicated in Table 21. The selected stakeholders were invited via email to participate in the interviews and were provided with information and an attached slideshow explaining the research (Appendix F). The stakeholders also signed a participant consent form. The day before each interview, the stakeholders were sent a customised slideshow with information on the WSC planning priorities and criteria from the pilot MCA linked to their expertise to ensure there was familiarity with the research.

The interviews were conducted both virtually and in-person and generally lasted around one hour in length. The interviews were not recorded to allow respondents to feel more comfortable and willing to participate in discussions. Given that a WSC transition is in its early stages in Cape Town and RSA and there are many challenging barriers and obstacles, the respondents were assured that their identities would not be disclosed to allow for a more honest discussion as water and sanitation provision in RSA is politically sensitive. Instead, detailed notes were taken as they responded to the questions. These notes were subsequently written up into non-verbatim transcription format. Appendix F shows the non-verbatim transcription for each interview.

7.3 Semi-structured interview responses

7.3.1 General questions

All seven respondents identified multifunctionality as a valuable and relevant concept for Cape Town. Some of the respondents emphasised that multifunctionality of infrastructure was critical to provide resilience and climate change adaptability. Multifunctionality also emerged as a financial argument, with respondents noting that if multiple functions could be provided from one piece of infrastructure there are more reasons to develop and repurpose it. The need for multifunctionality in areas that are densely settled was another factor identified particularly with regards to the existing stormwater ponds as the investment has already been made and the physical space occupied.

Respondents emphasised the need to consider and plan for multifunctionality upfront and in a strategic manner. They agreed that more resources are given to functions considered ‘basic services’ such as water, sanitation and flood control. They noted that it is challenging to focus on ‘nice-to-haves’ such as recreation and liveability when basic services are lacking, particularly in informal settlements. However, they highlighted the need to reframe ‘basic services’ to include liveability outcomes.

All the respondents felt that existing stormwater ponds could provide multifunctional benefits if transformed. Respondents highlighted the need to consider the location of the pond in the urban fabric and catchment context for multifunctionality, with different areas requiring different functions. Some stormwater ponds were noted to already be multifunctional. Examples were provided of infiltration and habitat for birds in retention ponds. One respondent regarded some stormwater ponds as being multifunctional for the wrong reasons, specifically as they are invaded for informal housing. Housing invasions (the term used by respondents) were cited by several respondents as a major concern, with significant accompanying social and environmental challenges. Respondents emphasised that the stormwater ponds are first and foremost flood control infrastructure, and that function always needs to be maintained and considered.

Whilst the value of transforming ponds into multifunctional BGI was acknowledged by all respondents, the challenges or barriers were highlighted as not only technical in nature but related to working arrangements and the people involved. Respondents stated that the technical arrangements of designing and constructing multifunctional ponds were relatively easy. The internal institutional issues and the management, maintenance and operations of the transformed pond over time were cited by every respondent as the most challenging issue to be overcome and posing significant barriers. One respondent noted that the issue is who does it, not whether it can or cannot be done.

The challenging issue of asset ownership and maintenance was identified by most respondents. The siloed nature of the city was viewed as a barrier particularly as stormwater was always a subset of the roads department. The issue of an organisational culture resistant to change was raised in this regard. The majority of the ponds (estimated by one respondent to be approximately 80%) are still owned and operated by the roads department, even though

stormwater is now its own department at the CCT. Stormwater is still viewed by a number of municipal staff as a nuisance and a risk that needs to be removed from the roads as quickly as possible.

The responses to the general questions provided input into the problem framing and not necessarily into the WSC planning priorities and criteria. Many of the factors highlighted assisted with the conceptualising and framing of multifunctional BGI however they were more limited in informing what should be measured in the MCA.

7.3.2 Cultural and heritage associations

The respondents regarded the WSC planning priority of ‘Enhancing cultural and heritage associations with water systems’ as important and necessary. They agreed that it is not always considered in projects as it should be. Respondents were asked specifically about the availability of culture and heritage datasets for Cape Town. They commented that any datasets would vary in quality and accuracy around the city and warned that some informal sites may be missing. Suggestions for datasets included using the CCT’s heritage overlay zones, the Cape Town map viewer which had graded heritage resources, and a local heritage sites dataset (City of Cape Town, 2019f, 2019h, 2019k). These datasets were used for the criterion in Section 8.2.

7.3.3 Increasing water re-use

Although only one of the seven respondents worked predominantly in the groundwater field, three more respondents were positioned to provide input into the ‘Increasing water re-use’ WSC planning priority. The primary inputs from the respondent that works in the groundwater field built directly on the example criterion of ‘MAR potential’ from the pilot MCA (Section 6.3). This criterion considered surficial geology, aquifer, transmissivity and soil permeability. The respondent advised using the surficial geology as a mask layer for the criterion (Section 8.3).

For aquifer presence and type, the respondent advised that the aquifers should be called either primary sand aquifer, rock aquifer and other groundwater or localised aquifer, rather than confined, semi-confined and no aquifer, and provided input on the performance scoring (Section 8.3). The respondent pointed out the need for framing MAR from a bulk water, citywide and resilience perspective. Aquifer characterisation is complex and nuanced and changes spatially over small areas. The transmissivity indicator and dataset were considered useful, but the respondent warned that it does not indicate direction of flow.

7.3.4 Climate change impacts

The respondents were asked if using stormwater ponds to either reduce the UHI effect or sequester carbon was a higher priority for the ‘Reducing climate change impacts’ WSC planning priority. All of the respondents regarded considering the UHI as very important. The first three

interviewees indicated that the UHI is an issue in Cape Town that the municipality is starting to grapple with. Additionally, one respondent noted that this is not the only planning priority to incorporate climate change, with many of the other planning priorities already considering climate change. After the first three interviews, the planning priority and associated questions were reframed for the UHI.

Respondents noted various aspects to consider for this planning priority including the variation in temperatures spatially across the city, the cell sizes for global land surface temperature datasets, and the impact of wind direction on the UHI. One respondent advised that there was a UHI intensity dataset that could be used for this criterion, which was obtained from the municipality (Section 8.4).

7.3.5 Education services

For the ‘Utilising education services potential’ WSC planning priority, the respondents viewed the ability to use stormwater ponds for educational purposes – specifically considering schools in close proximity to the ponds – as important. However, one respondent noted proximity to a pond does not necessarily mean it will be used by the school for educational purposes.

As the interviews progressed, respondents cited another benefit of having schools within close proximity to ponds, that of an opportunity for ownership or co-ownership and stewardship of the pond by the school. This would assist with keeping the pond better maintained and cared for. One respondent noted that learning does not just happen at schools but can also occur at community centres, non-governmental organisations (NGOs) and religious institutions. Incorporating religious institutions was highlighted as an important consideration as some religious groups use green spaces. The general link to community spaces both for educational and cultural purposes as well as for pond ownership and stewardship purposes emerged as an important factor.

7.3.6 Blue-green space

For the ‘Increasing access to blue-green space’ WSC planning priority, there was complete agreement among the respondents that walking distance access to blue-green space at ponds was more important than public transport access. Respondents felt that Cape Town residents would rather use public transport for an already established park that was perceived as safe and attractive than for a transformed stormwater pond. Respondents generally agreed that if ponds were near other existing amenities such as parks and sports facilities, it would be lower priority to transform those ponds to parks. The urban design principle of clustering or co-locating infrastructure and services was identified by respondents. For example, to prioritise ponds near to libraries and clinics. Respondents agreed that ponds with higher surrounding population densities should be prioritised for this benefit.

Some respondents suggested using pond size to assess if a soccer field or cricket pitch

could fit into the ponds when designing criteria. However, no input was given on the possible direction of preference for criterion scoring. While safety and security issues were regarded as an important practical consideration which may limit the potential to transform ponds, it was not considered necessary to include as a criterion at this scale. Some respondents suggested it be included in further research as a second order criterion or once a shortlist of prioritised ponds has been developed. Additionally, one respondent said that including safety and security issues too soon may be a disadvantage and result in less buy-in for transforming ponds. Another respondent felt that upgrading or transforming the ponds would be favourable especially in areas with high crime rates as it may lower crime rates and make the area more desirable which will enhance safety outcomes. Providing an amenity function was viewed as a way to perhaps manage invasions by informal settlements as the space would have value and a purpose. Safety in terms of drowning risks was also pointed out as a consideration for retention ponds.

7.3.7 Stormwater quality limitations

The ‘Incorporating stormwater quality limitations’ WSC planning priority was viewed as an important practical consideration. One respondent described it as ‘the elephant in the room’ that poses well known limitations but that is rarely included in a study. It was not viewed as an absolute dealbreaker for stormwater pond transformation into BGI but rather a risk and practical limiter and thus important to include as a criterion. The example criterion for this planning priority was ‘Proximity to informal settlement’. Respondents were asked to provide other land covers or activities that posed a stormwater quality risk. The first four interviewees provided more land covers and activities that could present a stormwater quality risk. It was suggested to frame such potentially polluting land covers as potentially contaminating activities (PCA).

The respondents provided virtually the same land covers and activities for PCAs. These included informal settlement land cover, WWTWs, landfill sites, industrial land cover and main transport routes, which were used in Section 8.7. One respondent noted that it is not always correct to ‘blame’ the land cover for poor stormwater quality but rather the way it is managed, and the services provided there. This highlighted the need for careful framing for this criterion.

The ‘Incorporating stormwater quality limitations’ WSC planning priority was framed to the respondents in the interview as a negative – as land covers that constrain functionalities because of poor stormwater quality – however, one respondent suggested an alternative emphasis. They stated that ponds near PCAs should be prioritised as they require transforming to improve stormwater quality. Another issue raised during this planning priority was the mixing of stormwater and sewage. Respondents agreed that stormwater in South Africa, and indeed in most Global South countries, also contains sewage.

7.3.8 Enhancing biodiversity

For the ‘Enhancing biodiversity’ WSC planning priority, the respondents felt that stormwater

ponds could contribute to the management, conservation and enhancement of biodiversity in the city – particularly if transformed in an ecologically sensitive manner. Respondents viewed stormwater ponds as having potential to provide ecological corridors, or to function as islands or stepping stones for movement of biodiversity. There was disagreement whether retention or detention ponds would provide more biodiversity, with some respondents stating that water immediately results in more aquatic biodiversity. Other respondents felt that vegetation alone has significant potential to contribute to ecosystem types such as indigenous grasslands. Using the ponds to enhance landscape connectivity was considered more important than the habitat size the ponds could provide. The city was viewed as already having large green spaces and nature reserves. Two respondents recommended the use of a CCT wetlands report and dataset which indicates biodiversity significance for use as the criterion, and which was used in Section 8.8 (Snaddon & Day, 2009).

7.3.9 Additional factors

Equity was regarded as an important factor and a defining feature of the context, but respondents did not feel that it required its own criterion. Respondents identified the difficulties with incorporating and measuring issues of equity through criteria for research at this scale using an MCA. Regarding the flood protection significance of the ponds, the general sentiment of respondents was to not include this as a criterion as it would be difficult to define a best- and worst-case scenario for performance scoring. Respondents highlighted that given that the original purpose of the ponds is to provide a flood control function, a criterion of this nature is not necessary.

Table 24 shows the proposed WSC planning priorities and criteria from Table 8 and the pilot MCA (Chapter 6) before and after the interviews. It shows how they were refined and reflects the value of the expert input. The framing of two WSC planning priorities were refined through the interviews: ‘Reducing climate change impacts’ became ‘Reducing the UHI effect’, and ‘Utilising education services potential’ became ‘Enhancing community services connection with water systems’.

7.4 Summary

This chapter described seven structured interviews conducted with WSC experts. The interviews provided both general and more specific input on refining the WSC planning priorities and selecting relevant contextual criteria and datasets. The following chapter uses this input to select criteria and score the ponds for the final MCA.

Table 24: The WSC planning priorities and proposed criteria pre-and post- the interviews

Pre-interviews		Post-interviews	
WSC planning priority	Proposed criteria	WSC planning priority	Proposed criteria
Enhancing cultural and heritage associations with water systems	Proximity to culture and heritage resource.	Enhancing cultural and heritage associations with water systems	Proximity to culture and heritage resource.
Increasing water re-use	Surficial geology, aquifer presence and type, transmissivity and soil permeability.	Increasing water re-use	Surficial geology (mask layer) aquifer type, transmissivity and soil permeability.
Reducing climate change impacts	Mean land surface temperature, Carbon sequestration rates for landcover.	Reducing the UHI effect	UHI risk.
Utilising education services potential	Euclidean distance to school.	Enhancing community services connection with water systems	Euclidean distance to school, community centre, religious institutions.
Increasing access to blue-green space	Mean population density in 500 m radius of each pond, Estimate of tract population without access to parks.	Increasing access to blue-green space	Mean population density in 500 m radius of each pond, proximity to existing amenities.
Incorporating stormwater quality limitations	Proximity to informal settlement.	Incorporating stormwater quality limitations	Proximity to PCAs (informal settlement land cover, industrial land cover, main transport route land cover, landfill, WWTW).
Enhancing biodiversity	Cape Town Biodiversity Network category presence, Habitat size.	Enhancing biodiversity	Biodiversity significance.

8. Criteria selection, scoring and trade-offs and synergies

This chapter describes the steps of criteria selection, data processing and scoring, with the individual criterion scores shown on maps, for the final MCA. It also assesses synergies and trade-offs between the criteria scores.

8.1 Criteria selection, data processing and scoring

Seven criteria were selected and organised under the WSC planning priorities to evaluate the potential for existing stormwater ponds to provide multiple benefits as BGI. The criteria were selected based on literature (Chapter 2), the proposed criteria in Table 8, the pilot MCA (Chapter 6) and the feedback from the semi-structured interviews (Chapter 7). The stormwater ponds dataset, refined in Section 5.4 (City of Cape Town, n.d.-d), in the CCT boundaries were the focus of the analysis. Publicly available and/or pre-processed datasets were favoured. This was to give the MCA a degree of generality; even though Cape Town's stormwater ponds are the focus, the BGI and WSC planning and decision support can be transferrable.

A proportional scoring approach was used for performance scoring, as described in Section 6.1 (Figure 50). Microsoft Excel, QGIS and ArcGIS Pro were used for data processing. Spatial queries and associated tools were used to extract criteria data for each pond and create individual criterion maps in GIS. Performance scoring was undertaken in Microsoft Excel. Synergy and trade-off patterns were assessed by calculating Pearson correlation coefficients between criterion scores in Microsoft Excel. The criterion, and associated selection rationale for each WSC planning priority, as well as the data sources and processing steps are described in Sections 8.2 to 8.8 and summarised in Table 25. Appendix G provides further detail on the dataset types and date(s).

8.2 Enhancing cultural and heritage associations with water systems

BGI can support and be a component of culture, heritage and indigenous sites in a city (Brown & Magoba, 2009; O'Brien *et al.*, 2017; Jackson & Moggridge, 2019). It can be developed in such a way that complements, enhances and strengthens associations with culture and heritage sites within a city (AFMAS solutions, 2019). The ecosystem services framework lists cultural ecosystem services as one of the four categories of services, alongside provisioning, regulating and supporting services (Millennium Ecosystem Assessment, 2005). They are defined as the non-material benefits people obtain from ecosystems and include links with societal processes such as cultural heritage values (Small *et al.*, 2017).

Table 25: Seven criteria organised under the seven WSC planning priorities

WSC planning priority	Criterion and data sources	Explanation
Enhancing cultural and heritage associations with water systems	Culture and heritage sites (City of Cape Town, 2019h, 2019k).	Intersection with national, provincial and local heritage resources indicates potential for the pond to contribute to conserving the heritage resource.
Increasing water re-use	MAR potential (Surficial geology (mask layer), Aquifer, Soil permeability and Transmissivity (Bailey & Pitman, 2012; Wright & Jacobs, 2016; World Agroforestry Centre Landscape Portal, 2021; City of Cape Town, n.d.-c).	Suitable conditions for MAR via surface infiltration are required.
Reducing the UHI effect	UHI intensity risk (land cover classes, daily normalised, irradiation and windspeed) (Petrie <i>et al.</i> , 2019).	The higher the UHI risk, the greater the need for cooling from BGI.
Enhancing community services connection with water systems	Proximity to schools, community centres and religious institutions (City of Cape Town, 2019e, 2019j; Department of Basic Education, 2021).	The closer to schools, community centres and religious institutions, the more community services reach and ownership and stewardship potential.
Increasing access to blue-green space	Recreation potential (two indicators of park presence and mean population density in 500 m pond radius (City of Cape Town, 2019i; Statistics South Africa, 2011)).	The presence of a park indicates a low recreation potential. The higher the population density, the higher the level of potential recreational use by people living in close proximity.
Incorporating stormwater quality limitations	Proximity to Potential Contaminating Activities (PCA) (informal settlement, industrial, roads, landfill, wastewater treatment works,) (City of Cape Town, 2019g, 2019m; Department of Forestry Fisheries and the Environment, 2021).	The further away from a PCA, the lower the likelihood for poor stormwater quality impacts to limit other potential functionalities.
Enhancing biodiversity	Aquatic biodiversity category (Snaddon & Day, 2009).	Biodiversity significance.

The ‘Culture and heritage sites’ criterion drew on a similar criterion used for an Ecosystem Service Assessment of natural vegetation remnants in Cape Town (O’Farrell *et al.*, 2012). It was based on the pond locations dataset and two culture and heritage related datasets: (1) the CCT Local Heritage Resources: Grade III (City of Cape Town, 2019h) from the pilot MCA (Section 6.2), and (2) the CCT Proposed Heritage Protection overlay, which designates areas of heritage significance identified in the CCT Environmental Management Framework of the Spatial Development Framework (City of Cape Town, 2019k).

The criterion was constructed using the ‘Join attributes by location’ tool with the

‘intersects’ geometric predicate. The ponds were assigned as present (i.e., the ponds intersected with the culture and heritage sites) or absent (i.e., the ponds did not intersect with the culture and heritage sites) from the datasets. Performance scoring was undertaken on the categories with ‘absent’ scoring zero and ‘present’ scoring one. Of the ponds, 15.1% were in the present category. This indicated the potential for the pond to contribute to protecting and enhancing culture, heritage and indigenous associations with water systems, due to its proximity to the site.

Table 26 and Figure 57 present the scoring of the ponds and their spatial distribution⁵ in the study area. Green ponds are those present in the culture and heritage datasets. They would be higher priority or offer more potential for the function of enhancing cultural and heritage associations with water systems. It indicates potential for the pond to be transformed in such a way that it can contribute to conserving the culture, heritage and indigenous resource. Furthermore, relevant culture, heritage and indigenous knowledge, concept and praxis could be considered and incorporated during the transforming.

Table 26: The ‘Culture and heritage sites’ criterion scores

Culture and heritage present/absent	Performance scale	Pond percentage
Absent	0	84.9%
Present	1	15.1%

8.3 Increasing water re-use

Stormwater harvesting via MAR is viewed as an increasingly viable means of augmenting urban water supply (Brown *et al.*, 2016; Carden & Fisher-Jeffes, 2017), with stormwater ponds offering existing storage opportunities. Stormwater ponds can facilitate MAR via surface infiltration (Dillon *et al.*, 2006; Armitage *et al.*, 2013; Beganskas & Fisher, 2017; Hamlyn-Harris *et al.*, 2018). Additional benefits of MAR include improving groundwater quality, preventing saltwater intrusion of coastal aquifers, mitigating floods and maintaining environmental flows for groundwater-dependent ecosystems (Mitchell *et al.*, 2007).

The ‘MAR potential’ criterion considered MAR via surface infiltration, through the stormwater ponds, from a citywide perspective towards resilience building. The criterion consisted of the four indicators of ‘Surficial geology’, ‘Aquifer’, ‘Soil permeability’ and ‘Transmissivity’ from the pilot MCA (Table 13). However, unlike the pilot MCA, surficial geology was treated as a mask layer and different performance scoring and indicator weightings

⁵ The maps showing the spatial distribution of the scores in Section 8.2 to 8.9 and Section 9.3 used the pond centroids to represent the ponds.

were used, as well as some different datasets.

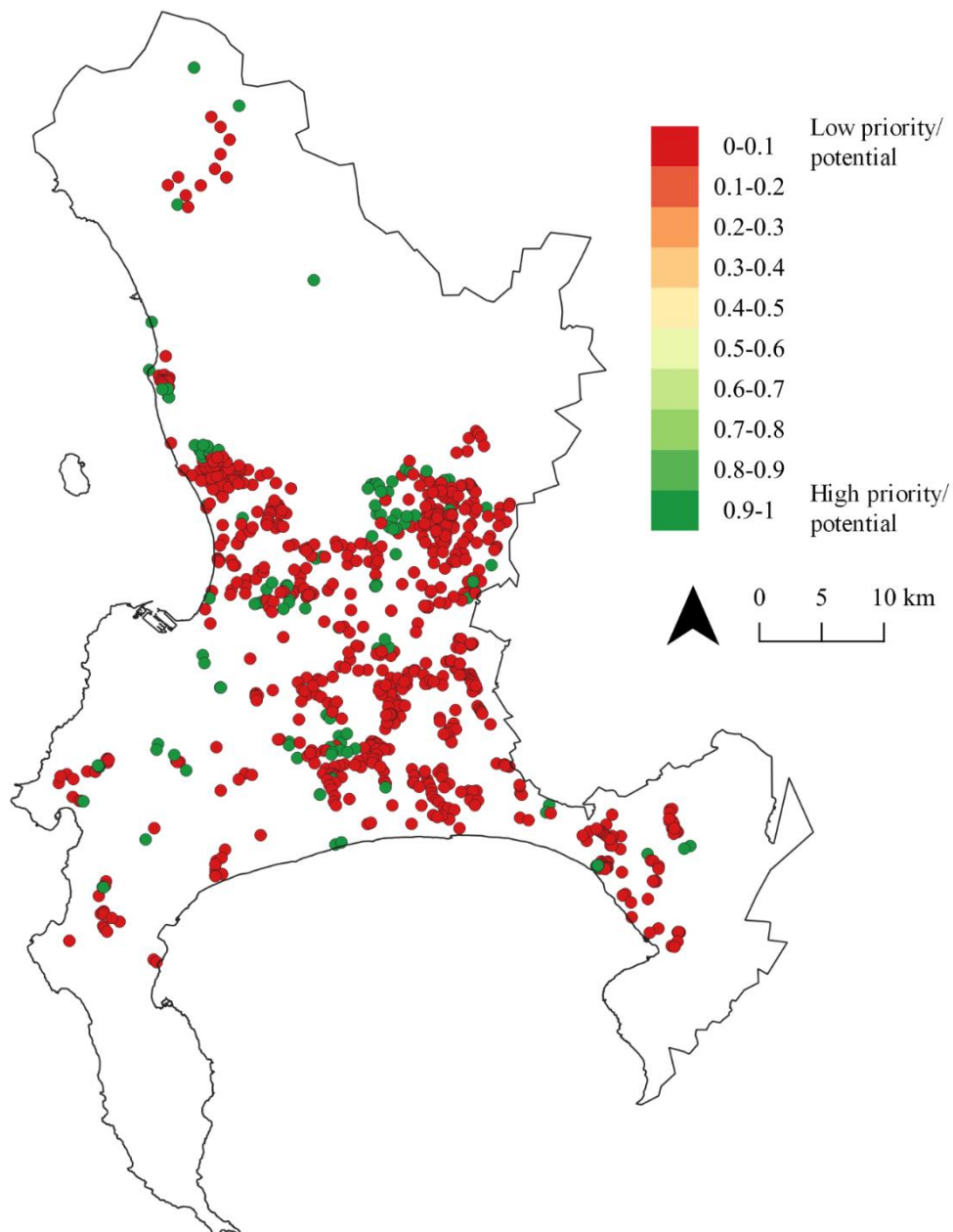


Figure 57: The spatial distribution of the ‘Culture and heritage sites’ criterion scores

The ‘Surficial geology’ indicator was constructed using the pond locations dataset and two surficial geology datasets that were combined (Bailey & Pitman, 2012; Wright & Jacobs, 2016). Feedback from the semi-structured interviews informed the scoring. The rock type and mean permeability of the surficial geology types were identified through the combined layers (Jasim et al., 2018). The ponds were assigned the surficial geology they intersected with using the ‘Join attributes by location’ tool with the ‘intersects’ geometric predicate (Table 27). The surficial

geology was used as a mask, with all ponds not assigned Quaternary sands masked out, on the recommendation of the groundwater expert interviewed in Chapter 7. Of the 848 ponds, 67% (568 ponds) overlie a Quaternary Sands surficial geology. Of the four surficial geology types, Quaternary sands with an alluvial rock type was the most suitable surficial geology for MAR via surface infiltration from stormwater ponds.

Table 27: The ‘Surficial geology’ indicator

Surficial geology	Rock type	Typical permeability (m ²)	Mean permeability (m ²)	Pond percentage
Cape Granite	Igneous	10 ⁻²⁰ –10 ⁻¹⁷	10 ^{-18.5}	4.5%
Malmesbury Shale	Sedimentary	10 ⁻²⁰ –10 ⁻¹⁶	10 ⁻¹¹	28.2%
Table Mountain Group Sandstone	Sedimentary	10 ⁻¹⁷ –10 ⁻¹⁶	10 ⁻¹⁵	0.4%
Quaternary Sands	Alluvial	10 ⁻¹³ –10 ⁻⁹	10 ⁻¹¹	67.0%

The ‘Aquifer’ indicator was constructed using the pond locations dataset and the City of Cape Town Metropolitan Municipality ‘delineated aquifer zones targeted to develop wellfields’ dataset (City of Cape Town, n.d.-a). This dataset was different from the one used in the pilot MCA. Feedback from the semi-structured interviews informed the scoring. The ponds were assigned the delineated aquifer zones using the ‘Join attributes by location’ tool with the ‘intersects’ geometric predicate. For scoring, ponds overlying a primary sand aquifer were assigned a score of one and all other ponds were assigned a score of 0.1 as they overlie localised groundwater, on the recommendation of the groundwater expert interviewed in Chapter 7. Table 28 shows the aquifer type, performance scoring and pond percentage among Quaternary Sands surficial geology.

Table 28: The ‘Aquifer’ indicator scores

Aquifer type	Performance scale	Pond percentage (among Quaternary Sands surficial geology)
Primary sand aquifer	1	48.6%
Localised groundwater	0.1	51.4%

The ‘Soil permeability’ indicator was constructed using the pond locations and the International Soil Reference and Information Centre (ISRIC) Soil and Terrain (SOTER) database soil map (World Agroforestry Centre Landscape Portal, 2021). The soil types were described with the aid of the Food and Agriculture Organisation of the United Nations (FAO) classification system. This system uses Soil Reference Groups and Qualifiers to assign soil type based on properties

and composition. Soil composition and drainage characteristics from the SOTER dataset were then estimated by classifying the soil types into Hydrological Soil Groups (HSGs) and associated hydraulic conductivity ranges (Table 29) (United States Department of Agriculture, 2007). The selected hydraulic conductivity values were used to normalise the soil types onto the performance scale. ARa was assigned a suitability value of one as it was the most suitable soil for infiltration. All other scores were assigned proportionally.

Table 29: The ‘Soil permeability’ indicator process and scores

Soil type (FAO Soil Unit Codes)		Hydrological Soil Group	Saturated hydraulic conductivity range **(µm/s)	Selected saturated hydraulic conductivity (µm/s)	Performance scale	Pond percentage (among Quaternary Sands surficial geology)
Ach	Haplic Acrisols	B/C	<10→4.0 or <4.0→0.4	4.0	0.36	1.4%
ARa	Albic Arenosols	A*	>10	11	1	65.7%
LPq	Lithic Leptosols	C	<10→1.0	5.5	0.5	3%
LVh	Haplic Luvisols	B	<10→4.0	6.25	0.57	0%
LXh	Haplic Lixisols	B	<10→4.0	7.6	0.69	1.2%
Ple	Eutric Planosols	B	<10→4.0	6.7	0.61	1.4%
PZh	Haplic Podzols	A/B	>10 or <10→ >4.0	10	0.9	27.3%

*ARa was assigned to HSG A, as its sand percentage was very close to 90% and its clay proportion was within the correct range.

** Saturated Hydraulic Conductivity is provided for the least transmissive layer.

The ‘Transmissivity’ indicator used the pond locations dataset and transmissivity categories from the Water Resources 2012 Study (Bailey & Pitman, 2012). The ponds were assigned the transmissivity band they intersected with using the ‘Join attributes by location’ tool with the ‘intersects’ geometric predicate. Scoring was applied to the rates of flow in the transmissivity categories. The transmissivity categories included the media through which groundwater flow occurs – intergranular flow or through fractures in rock, as well as the rate of flow of water through the medium. For MAR via infiltration ponds, intergranular flow is thought to be the most desirable, as fractured rock flow is more characteristic of confined aquifers. However, only the rate of flow of water was used for value scaling, as the soil permeability indicator already considers infiltration. The highest transmissivity rate (>5.0 l/s) was assigned a value of one. All

others were scored proportionately with the mean value of each range as the reference point, as detailed in Table 30.

Table 30: The ‘Transmissivity’ indicator scores

Transmissivity		Mean of range	Performance scale	Pond percentage (among Quaternary Sands surficial geology)
Fractured	0.0–0.1 l/s	0.05	0.01	0%
Intergranular and fractured	0.0–0.1 l/s	0.05	0.01	1.9%
Fractured	0.1–0.5 l/s	0.3	0.06	0%
Intergranular and fractured	0.1–0.5 l/s	0.3	0.06	0%
Intergranular	0.1–0.5 l/s	0.3	0.06	38.4%
Fractured	0.5–2.0 l/s	1.25	0.25	16.4%
Intergranular	0.5–2.0 l/s	1.25	0.25	24.3%
Fractured	2.0–5.0 l/s	3.5	0.7	0%
Intergranular	2.0–5.0 l/s	3.5	0.7	18.1%
Intergranular	>5.0 l/s	5	1	0.9%

The ‘MAR potential’ criterion was then constructed through the four indicators. The ‘Surficial geology’ was used as a mask, with all ponds not assigned Quaternary sands masked out. The scores from the other three indicators – ‘Aquifer’, ‘Soil permeability’ and ‘Transmissivity’ – were combined with the weightings in Table 31 using Equation 1 of the weighted additive model to produce the ‘MAR potential’ criterion.

A point allocation method was adopted for the weighting. It drew on guidance from Russo & Fisher (2015) who advocate for equal weightings or weightings within a small range of variability, usually of 0.1, for MAR suitability studies. Additionally, domain expert input was obtained for the weighting. The ‘Aquifer’ indicator was assigned the highest weighting as the presence of a primary sand aquifer is essential for MAR via surface infiltration. This decision was also supported by Dupont (2018), where hydrogeology was assigned the highest weighting out of the selected criteria. As the ‘Aquifer’ indicator reflects data included in the ‘Transmissivity’ indicator, the ‘Transmissivity’ indicator was not assigned as great a weighting. However, it was ensured that the indicator remained within the common variability range of 0.1 being assigned a weighting of 0.28 (Russo & Fisher, 2015). Sallwey *et al.* (2019) showed that for spreading methods, the presence of hydrological soils was often deemed of critical importance, second only to hydrogeology. Therefore, ‘Soil permeability’ was deemed to be an important indicator, as reflected by its weighting.

Table 32 and Figure 58 present the scoring of the ponds and their spatial distribution in the

study area. Darker green ponds (with higher criterion scores) are those with the most suitable conditions related to surficial geology, aquifer, transmissivity and soil type. They would be higher priority or offer more potential if the goal is to increase water re-use through MAR.

Table 31: The ‘MAR potential’ indicator weightings

Indicator	Weighting
Aquifer	0.38
Soil permeability	0.33
Transmissivity	0.28

Table 32: The ‘MAR potential’ criterion scores

MAR potential	Performance scale	Pond percentage
MAR potential low	0–0.2	33.0%
MAR potential low-medium	0.2–0.4	19.8%
MAR potential moderate	0.4–0.6	12.7%
MAR potential moderate-high	0.6–0.8	22.1%
MAR potential high	0.8–1	12.4%

8.4 Reducing the Urban Heat Island effect

Urban areas are associated with higher temperatures, which have various negative consequences on human and ecosystem health (Antoszewski *et al.*, 2020; Shao & Gunwoo, 2022). Densely populated urban areas can experience temperatures that are up to 5°C higher than surrounding suburban or rural areas (Taha, 1997). BGI can moderate the UHI effect, the impact of which is projected to worsen with climate change in many areas (Akbari *et al.*, 2016; Simperler *et al.*, 2020). For example, increasing greenery in parks can reduce peak surface temperatures by 2–9°C, however the cooling potential is dependent on the shape and size of the greenery extent (Wong *et al.*, 2021).

An UHI intensity dataset developed by Petrie *et al.* (2019) for a Cape Town climate change risk and vulnerability assessment was used for the ‘UHI intensity’ criterion. The dataset was recommended by one of the WSC experts during the semi-structured interviews (Chapter 7). It consisted of three ranked and combined input layers: (1) land cover classes which were given heat scores ranging 1–9 (9=hot), (2) daily normalised irradiation reclassified 1–9, and (3) mean annual wind speed reclassified 1–9 where 1=high wind speed (cooling) and 9=low wind speed (hot conditions). The UHI intensity map had a nine-category scale indicating intensity with one being low and nine being high.

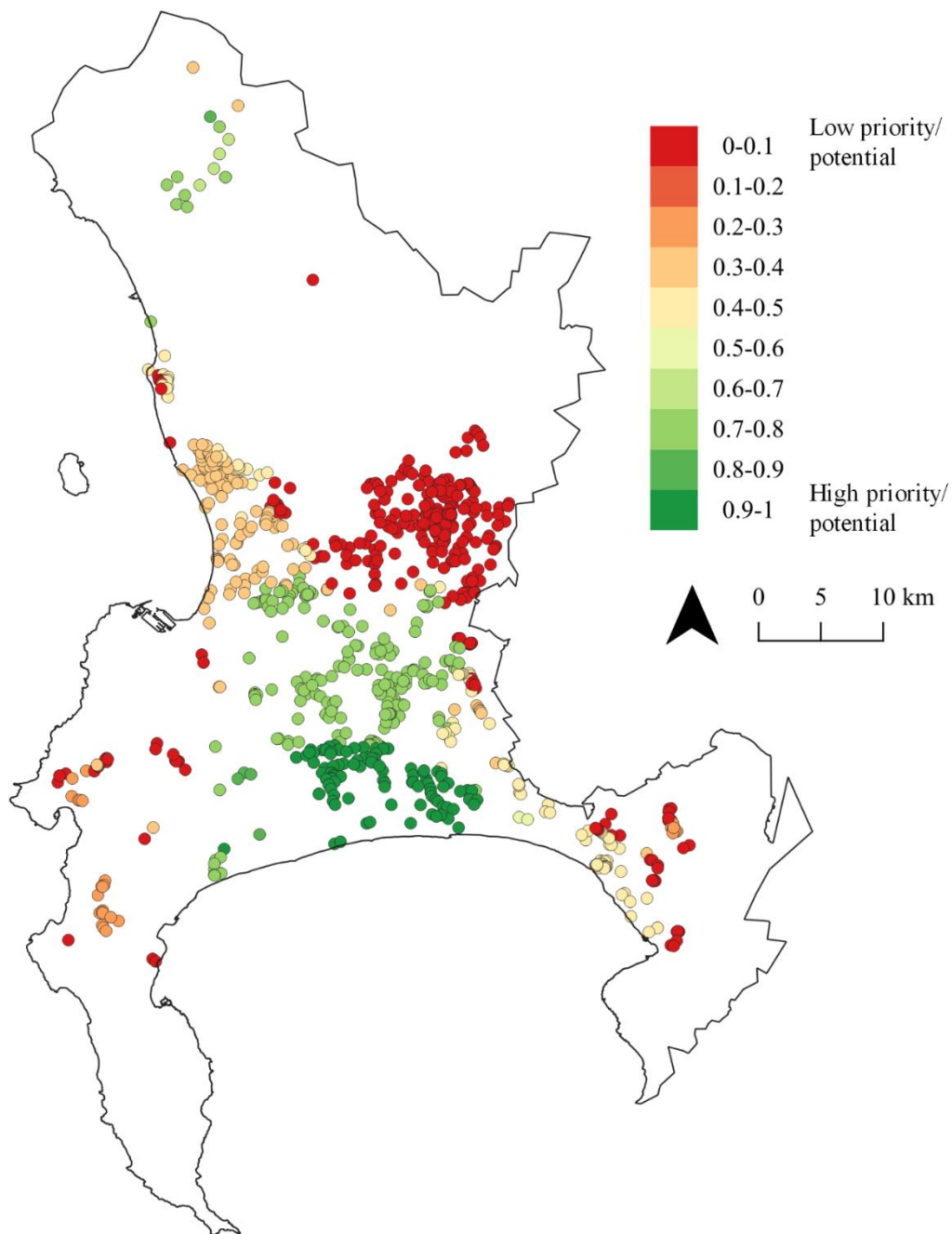


Figure 58: The spatial distribution of the ‘MAR potential’ criterion scores

For the ‘UHI intensity’ criterion, the ponds were assigned a value from one (low heat island intensity) to nine (high heat island intensity) from the nine-category scale of the UHI intensity dataset. This was done using the ‘Join attributes by location’ tool and the ‘intersects’ geometric predicate. The performance scoring used the nine-category scale, with ponds assigned nine for ‘high heat island intensity’ scoring one and ponds assigned one for ‘low heat island intensity’ scoring zero. Ponds corresponding with a high heat island intensity indicate the need for UHI mitigation and were thus scored one.

Figure 59 and Table 33 present the scoring of the ponds and their spatial distribution in the study area. Darker green ponds (with higher criterion scores) are those with higher heat island intensity scores. They would be higher priority for multifunctional BGI transforming as the need for UHI mitigation is the highest.

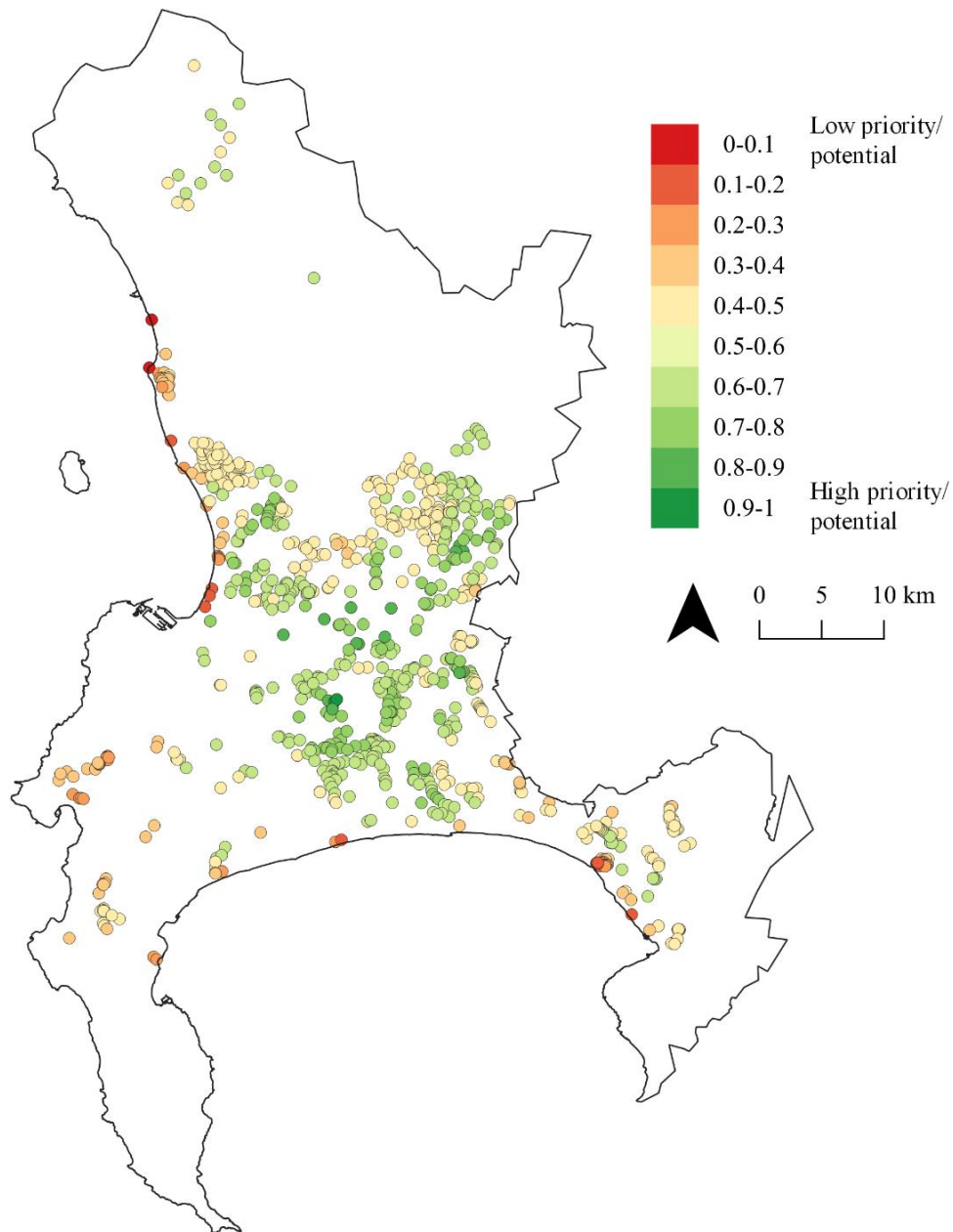


Figure 59: The spatial distribution of the ‘UHI intensity’ criterion scores

Table 33: The ‘UHI intensity’ criterion scores

UHI intensity score	Performance scale	Pond percentage
1(low heat island intensity)	0	0.2%
2	0.125	1.4%
3	0.25	3.3%
4	0.375	8.5%
5	0.5	36.4%
6	0.625	35.8%
7	0.75	12.3%
8	0.875	1.8%
9 (high heat island intensity)	1	0.2%

8.5 Enhancing community services connection with water systems

BGI can provide cultural services to surrounding communities. It can provide various opportunities related to education about water systems and the environment, space to pursue religious or cultural rituals and enhanced (Yli-Pelkonen & Niemelä, 2005; Plieninger *et al.*, 2013; Kati & Jari, 2016).

A criterion of ‘Proximity to schools, community centres and religious institutions’ was selected, drawing on input from the semi-structured interviews to include these types of organisations as beneficiary surrounding communities. Furthermore, it was informed by a criterion used by O’Farrell *et al.* (2012) of ‘proximity (1 km walking distance) of vegetation remnants to schools’ in a Rapid Ecosystem Service Assessment.

In addition to BGI having potential to provide cultural services to surrounding communities, the ownership or stewardship of BGI by beneficiary or surrounding communities can enhance the success of BGI (Everett & Lamond, 2018; Thorne *et al.*, 2018). Feedback from the semi-structured interviews emphasised the need for this criterion to incorporate both cultural services provision and pond ownership and stewardship opportunities offered by beneficiary surrounding communities.

The criterion of ‘Proximity to schools, community centres and religious institutions’ used the pond locations dataset and a merged dataset comprised of schools, community centres and religious institutions locations (City of Cape Town, 2019e, 2019j; Department of Basic Education, 2021). The Euclidean distance from the ponds to the nearest school, community centre or religious institution was calculated using the Nearest Neighbour Join (NNJoin) Plugin. A linear score range was applied to the distances, with a score of one assigned to the pond nearest to a school, community centre or religious institution as these have good potential for cultural services provision/reach and pond ownership and stewardship.

Figure 60 and Table 34 present the scoring of the ponds and their spatial distribution in the study area. Table 35 shows the nearest community service type to the ponds. Darker green ponds (with higher criterion scores) are those closer to schools, community centres and religious institutions. They would be higher priority or offer more potential for community services connection with water systems.

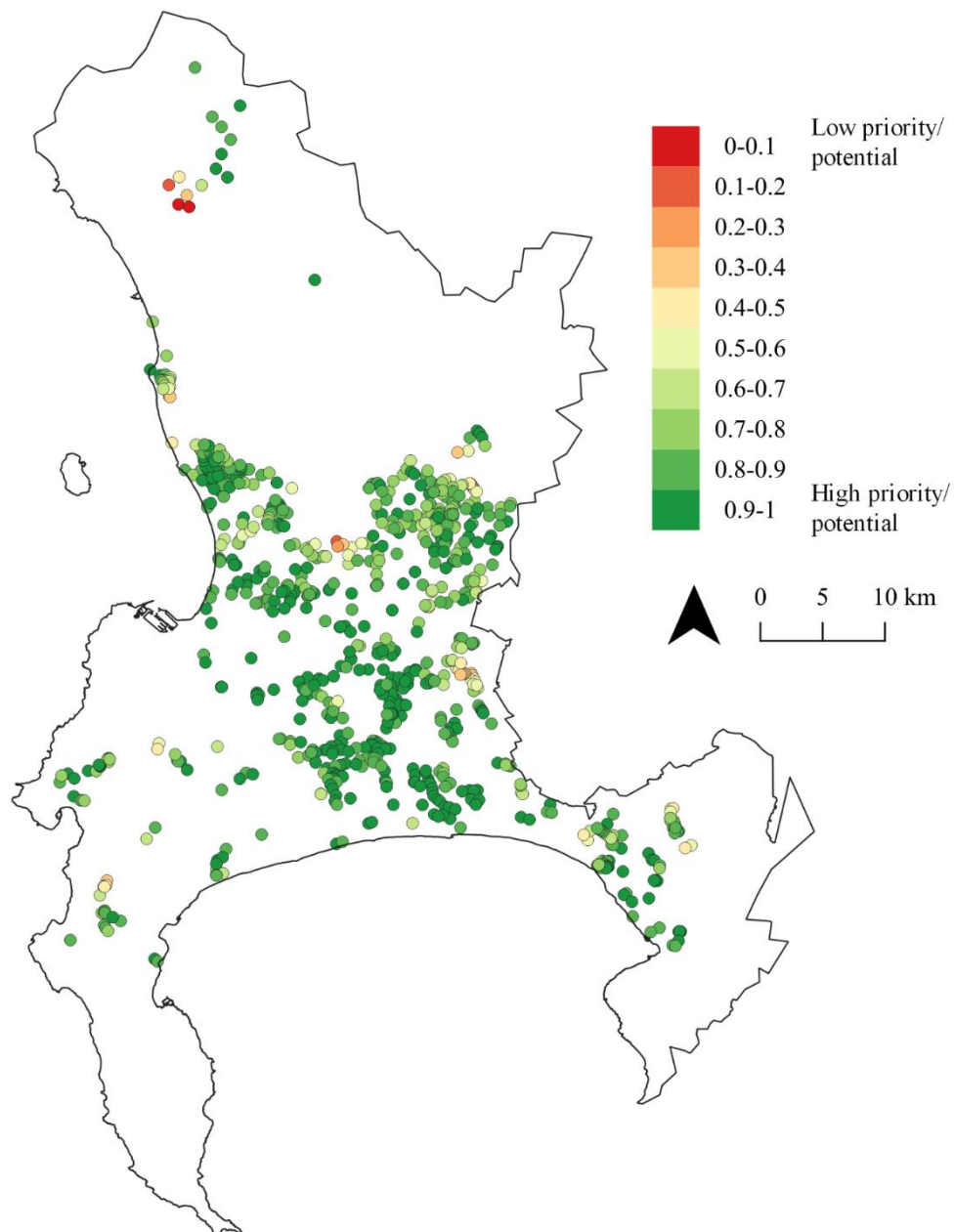


Figure 60: The spatial distribution of the ‘Proximity to schools, community centres and religious institutions’ criterion scores

Table 34: The ‘Proximity to schools, community centres and religious institutions’ criterion scores

Distance to school, community centre or religious institution (m)	Performance scale (mean)	Pond percentage
0–290	1	36.0%
290–580	0.9	30.0%
580–870	0.8	17.7%
870–1160	0.7	7.7%
1160–1450	0.6	3.1%
1450–1740	0.5	2.6%
1740–2030	0.4	1.8%
2030–2320	0.3	0.7%
2320–2610	0.2	0.2%
2610–2900	0.1	0.1%
2900–3190	0	0.2%

Table 35: The nearest community service type to the ponds

Community service type	Pond percentage
Schools	56.4%
Community centres	6.0%
Religious institutions	37.6%

8.6 Increasing access to blue-green space

Urban blue-green spaces offer a range of potential benefits detailed extensively in the literature including recreation and amenity, enhanced liveability or attractiveness of an area, emotional and mental health benefits (Burkhard *et al.*, 2012; Hansen & Pauleit, 2014; Kremer *et al.*, 2016).

Increasing access to blue-green space was measured through the criterion of ‘Recreation potential’, drawing on indicators used by Kremer *et al.* (2016), Meerow & Newell (2017) and Morgan & Fenner (2019). The criterion incorporated both supply and demand for blue-green space for recreation, considering the presence of existing parks to represent areas of supply and mean population density to represent areas of demand (Liu *et al.*, 2020). For the ‘Recreation potential’ criterion, pond centroids were created, and a 500 m buffer was computed. The criterion consisted of two indicators outlined in Table 36, with the ‘Mean population density’ indicator from the pilot MCA used (Section 6.4).

Table 36: The two indicators for the ‘Recreation potential’ criterion

Recreation potential	Explanation
Park presence	The presence of an existing park within a 500 m radius of a pond indicates a low recreation potential. Park presence was treated as a mask layer for the recreation potential criterion.
Mean population density within 500 m of pond	The mean population density within 500 m of the pond indicates the level of potential use of the pond by people living in close proximity to it.

The ‘Park presence’ indicator assessed park presence within a 500 m radius of each pond, with the presence of an existing park indicating a low recreation potential. Morgan & Fenner (2019) note that *‘a new area of green space in an area with very little existing green space may have a transformational effect in that location while in another area with plenty of green space the same intervention may convey little or no relative additional benefit at all’*. The park presence dataset was developed by selecting parks from an existing Parks dataset (City of Cape Town, 2019i) that were listed and categorised on the City of Cape Town Metropolitan Municipality’s ‘*Recreation and Parks Department*’ webpage as ‘District parks’, ‘Outdoor gyms’, ‘Regional parks’, and ‘Spray parks’ (City of Cape Town, n.d.-c). These park categories were selected to indicate public accessibility, free entry, and maintenance and management by the municipality – aspects related to park quality. The ponds were assigned presence or absence of a park within a 500 m radius using the ‘Join attributes by location’ tool with the ‘intersects’ geometric predicate (Table 37). Park presence was used as a mask, with all ponds intersecting a park within a 500 m radius masked out to indicate low recreation potential due to the presence of an existing park.

Table 37: The ‘Park presence’ indicator

Park present/absent	Pond percentage
Present	10.5%
Absent	89.5%

The development of the ‘Mean population density within 500 m of pond’ indicator was described in Section 6.4 of the pilot MCA.

For the ‘Recreation potential’ criterion, Figure 61 and Table 38 present the scoring of the ponds and their spatial distribution in the study area. Darker green ponds (with higher criterion scores) are those with higher population densities and no parks present within a 500 m radius. They would be higher priority or offer more potential if the goal is to increase access to blue-green spaces for recreation.

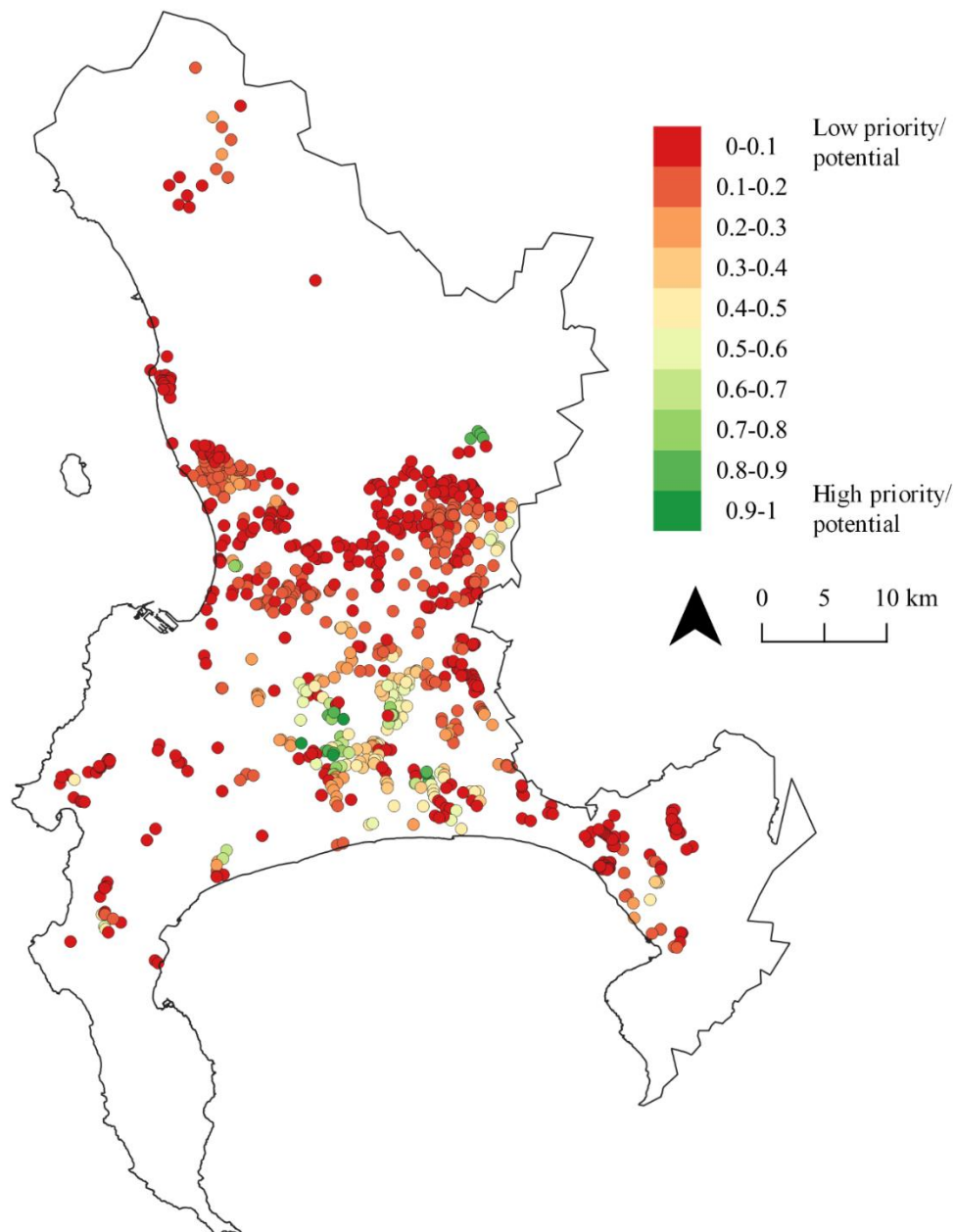


Figure 61: The spatial distribution of the ‘Recreation potential’ criterion scores

8.7 Incorporating stormwater quality limitations

Poor stormwater quality limits the potential functions of BGI, posing restrictions on MAR, biodiversity and amenity functions (Mitchell *et al.*, 2006; Alan Plummer Associates., 2010; Nyenje *et al.*, 2010; Armitage, 2011; Capps *et al.*, 2016; Jiusto & Kenney, 2016). Incorporating stormwater quality limitations that would limit functionality of the stormwater ponds was assessed through the criterion of the pond proximity to potentially contaminating activities (PCA) – activities or land covers that are typically associated with poor stormwater quality.

Table 38: The ‘Recreation potential’ criterion scores

Mean population density (per hectare) and park presence within 500 m of pond	Performance scale (mean)	Pond percentage
Park present	0	10.5%
0–22	0.0	36.6%
22–44	0.1	27.0%
44–66	0.2	8.0%
66–88	0.3	4.7%
88–110	0.4	4.5%
110–132	0.5	2.8%
132–154	0.6	2.5%
154–176	0.7	1.1%
176–198	0.8	1.3%
198–220	0.9	0.7%
220–242	1.0	0.4%

PCAs were identified from feedback from the semi-structured interviews (Chapter 7) and literature. Landfill sites, wastewater treatment works and informal settlement, industrial and roads land cover were selected as the PCAs. Stormwater quality is dependent on site conditions, land covers, activities and the state of infrastructure in a catchment (Mitchell *et al.*, 2006; Butler & Davies, 2011). Industrial land cover and roads are typically associated with an increased likelihood of pollution of stormwater (Alan Plummer Associates., 2010; Schoeman *et al.*, 2001). Kuller *et al.* (2017) used the indicators of ‘Regular solid waste collection Yes/No’, ‘Advanced sanitation/open defecation’ and ‘(Distance to) landfill sites’ to indicate limiting water quality factors for WSUD technology development. Informal settlement land cover is typically associated with poor stormwater quality due, in part, to limited sanitation, drainage and solid waste collection service provision (Nyenje *et al.*, 2010; Monney *et al.*, 2013; Capps *et al.*, 2016). In RSA, runoff from informal settlements is often a toxic cocktail of stormwater, sewage and solid waste – which ultimately enters the stormwater network and in turn stormwater ponds (Armitage, 2011; Jiusto & Kenney, 2016). Ponds within close proximity to the PCAs of landfill sites, wastewater treatment works and informal settlement, industrial and roads land cover may thus have more limited functions due to poor stormwater quality.

The ‘Proximity to potential contaminating activities’ criterion was constructed using the pond locations dataset and a PCA dataset comprised of the following five merged datasets: (1) Landfill sites (City of Cape Town, 2019g), (2) WWTWs (City of Cape Town, 2019m), (3) informal settlement land cover (Department of Forestry Fisheries and the Environment, 2021), as used in the pilot MCA (Section 6.5), (4) industrial land cover (Department of Forestry Fisheries and the Environment, 2021), and (5) roads land cover (Department of Forestry Fisheries and the Environment, 2021). The land cover datasets were from the South African National Land

Cover 2020 dataset and were vectorised for the criterion (Department of Forestry Fisheries and the Environment, 2021). The Euclidean distance from the ponds to the nearest PCA was calculated using the Nearest Neighbour Join (NNJoin) Plugin. A linear score range was applied to the distances, with a value of one (best case scenario) assigned to the pond with the longest distance to a PCA – which would be relatively less likely to be impacted by poor stormwater quality as it is furthest from a PCA. Thus, it would be relatively less likely to have poor stormwater quality impact potential functionalities such as MAR, biodiversity and amenity.

Table 39 and Figure 62 present the scoring of the ponds and their spatial distribution in the study area. Table 40 shows the nearest PCA to the ponds. Darker green ponds (with higher criterion scores) are those with relatively longer distances to PCAs – which indicate more potential for multifunctionality (MAR, biodiversity and amenity) as they would be less constrained by stormwater quality impacts.

Table 39: The ‘Proximity to PCAs’ criterion scores

Distance to PCAs (m)	Performance scale (mean)	Pond percentage
0–200	0	46.2%
200–400	0.1	15.6%
400–600	0.2	11.2%
600–800	0.3	8.8%
800–1000	0.4	6.7%
1000–1200	0.5	5.8%
1200–1400	0.6	3.3%
1400–1600	0.7	0.9%
1600–1800	0.8	0.7%
1800–2000	0.9	0.1%
2200–2400	1	0.6%

Table 40: The nearest PCA to the ponds

PCAs	Pond percentage
Landfills	1.3%
Informal settlement Land cover	32.5%
Industrial Land cover	47.3%
Roads Land cover	17.7%
WWTW	1.2%

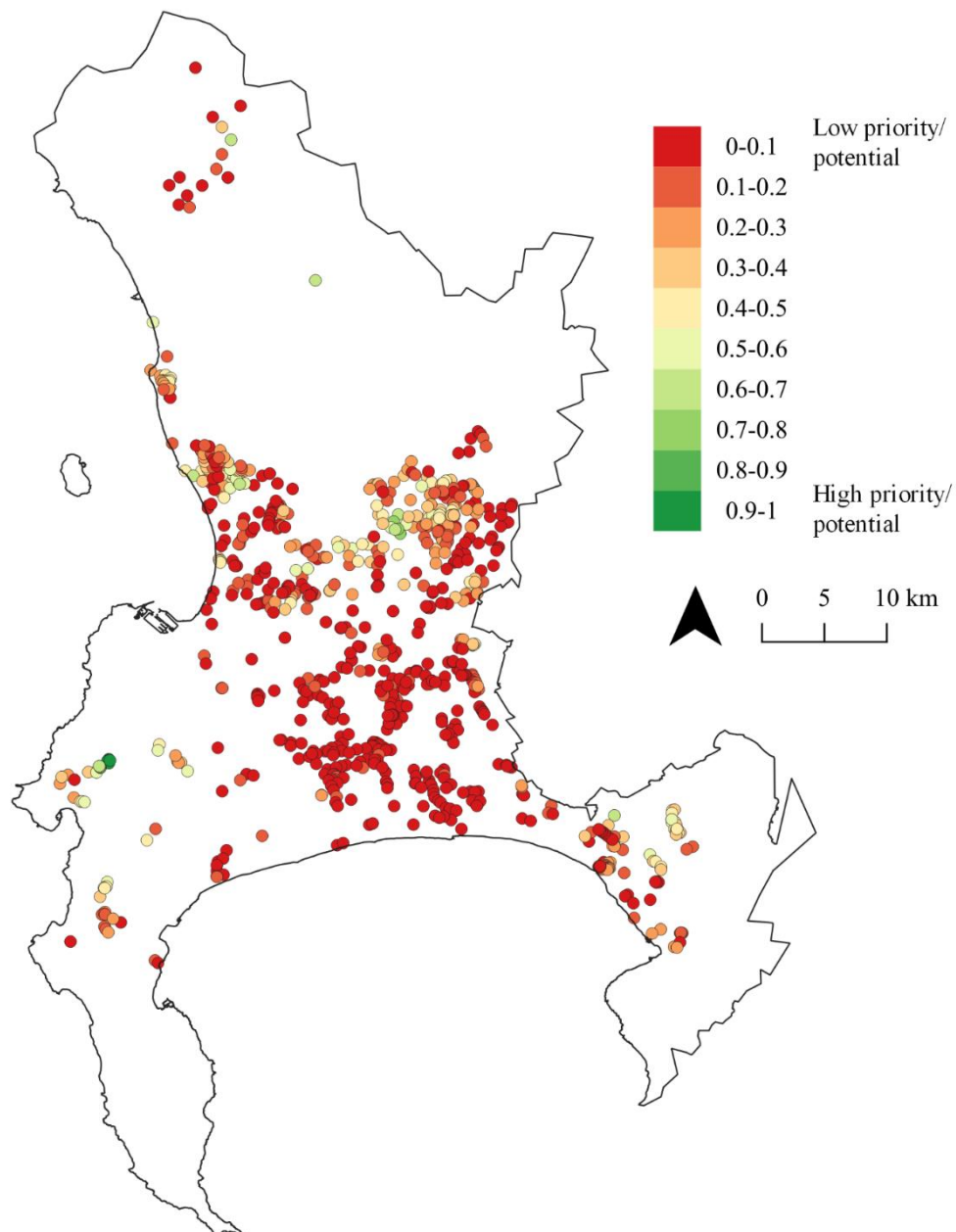


Figure 62: The spatial distribution of the ‘Proximity to PCAs’ criterion scores

8.8 Enhancing biodiversity

BGI can provide habitat space, refuge and resources for biodiversity, as well as contribute to conservation (Breuste *et al.*, 2013; Cilliers *et al.*, 2013; Sikorski *et al.*, 2021). Stormwater ponds can be transformed to enhance biodiversity, especially if they have existing biodiversity significance. The biodiversity criterion was based on the CCT ‘Prioritisation of City Wetlands’ dataset (Snaddon & Day, 2009). The dataset prioritises city wetlands through ranking or valuing them according to their contribution to the conservation of biodiversity pattern and process. Aquatic biodiversity categories that aligned with CCT’s Cape Town Bioregional Plan Policy

were used in the dataset (City of Cape Town, 2015).

The ‘Aquatic biodiversity category’ criterion was constructed with the pond locations dataset and the ‘Prioritisation of City Wetlands’ dataset, using the ‘Join attributes by location’ tool with the ‘intersects’ geometric predicate (City of Cape Town, 2019n). The ponds were assigned their corresponding aquatic biodiversity category from the ‘Prioritisation of City Wetlands’ dataset and the associated report (Snaddon & Day, 2009; City of Cape Town, 2019d). Scoring was applied according to the aquatic biodiversity categories and their stated biodiversity significance. The ‘Prioritisation of City Wetlands’ report states the relative importance of the different categories, with the hierarchy shown in the list (Table 41) (Snaddon & Day, 2009). A score of zero (worst case) was assigned to stormwater ponds that did not feature in the ‘Prioritisation of City Wetlands’ dataset and thus did not have an aquatic biodiversity category.

Table 41: The aquatic biodiversity categories (Snaddon & Day, 2009)

Aquatic biodiversity categories	Explanation
Critical Biodiversity Area 1 (CBA1)	Very high ranking ‘natural or semi-natural’ wetlands (and estuaries).
Critical Biodiversity Area 2 (CBA2)	High ranking ‘natural or semi-natural’ wetlands; all remaining estuaries.
Critical Ecological Support Areas (CESA)	High ranking artificial wetlands; middle ranking natural or semi-natural wetlands.
Other Ecological Support Areas (OESA)	Lower ranking artificial wetlands; lowest ranking natural or semi-natural wetlands.

Table 42 and Figure 63 present the scoring of the ponds and their spatial distribution in the study area. Darker green ponds (with higher criterion scores) are those in a relatively more important aquatic biodiversity category, and would be higher priority or offer more potential if the goal is to enhance biodiversity. They would be higher priority for transformation and could be done in a way that enhances biodiversity.

Table 42: The ‘Aquatic biodiversity category’ criterion scores

Aquatic biodiversity categories	Performance scale	Pond percentage
Not present/categorised	0	32.3%
OESA	0.25	59.0%
CESA	0.5	6.4%
CBA2	0.75	1.4%
CBA1	1	0.9%

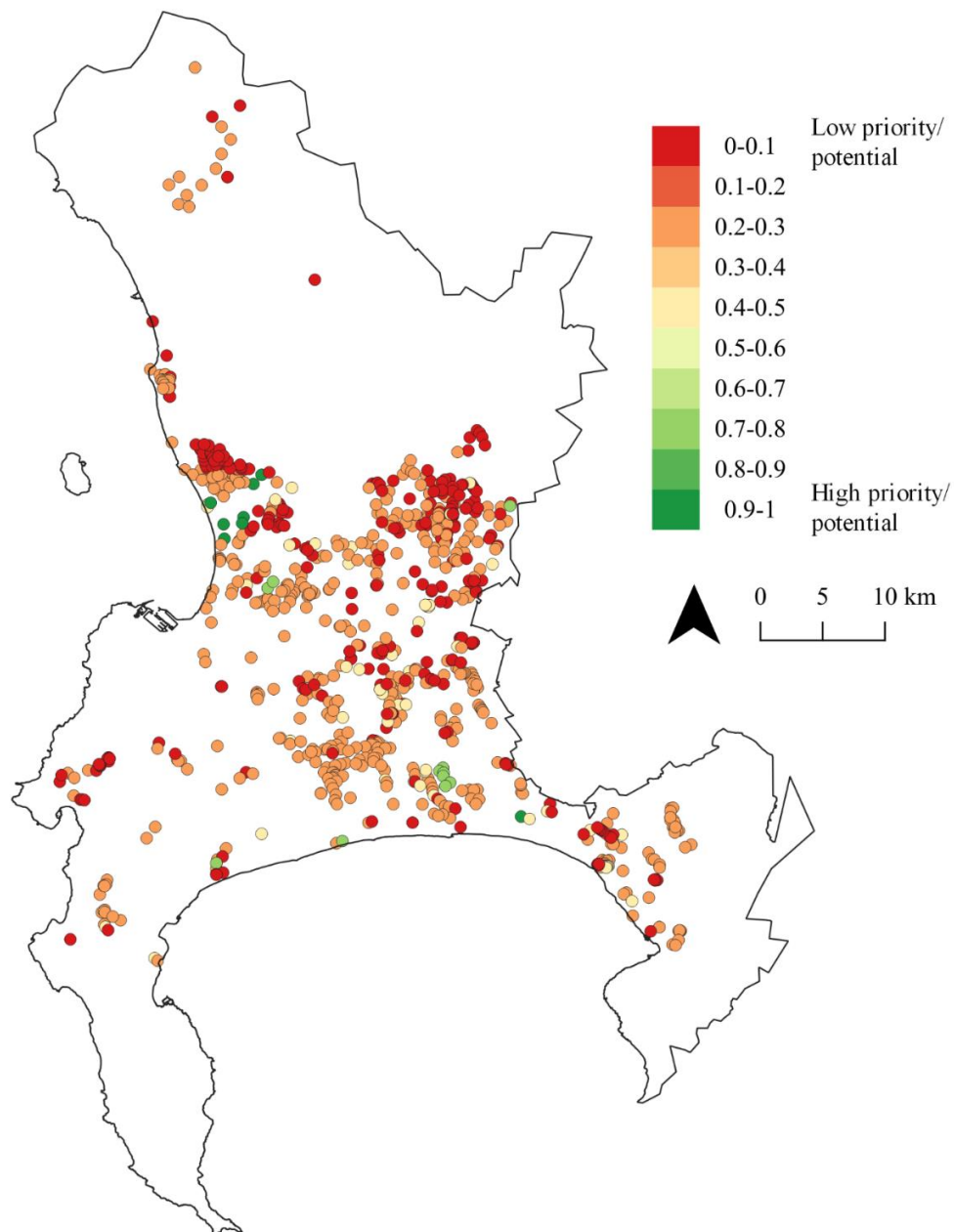


Figure 63: The spatial distribution of the ‘Aquatic biodiversity category’ criterion scores

8.9 Individual criterion maps

The seven criterion maps are shown together in Figure 64. There was a low potential for ‘Enhancing cultural and heritage associations with water systems’, with only 15,1% of the ponds intersecting with a culture and heritage resource (Table 26). A hotspot of the highest ‘MAR potential’ ponds coloured darker green is evident in the southern central part of the city. There is another hotspot of higher MAR potential ponds coloured in lighter green directly above it. Of the ponds, 34.5% show a moderate-high to high potential for MAR (Table 32).

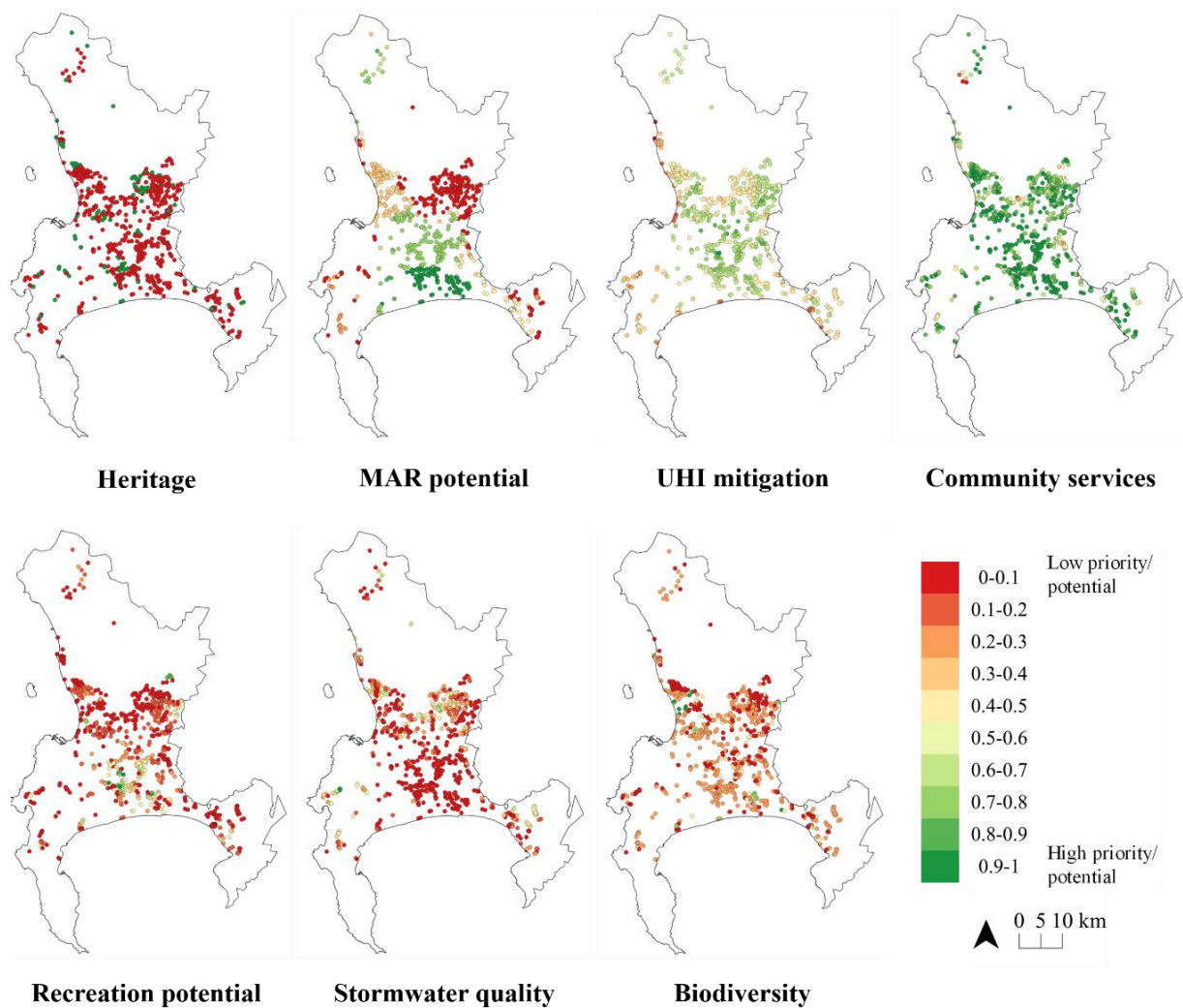


Figure 64: Seven criterion maps showing the relative benefit potential or prioritization

For reducing the UHI effect, just over half of the ponds have a ‘UHI intensity’ score in the highest categories between 0.6–1, coloured light green to darker green, and thus are high priority for UHI mitigation (Table 33). These ponds appear to be concentrated in the central parts of the city. ‘Community services connection with water systems’ reveals many ponds with high potential for this benefit, with 66% of the ponds in the top two potential categories, being within 580 m of a school, religious institution or community centre (Table 34). The closest community connection with the ponds was schools at 56.4%, with religious institutions the next closest at 37.6% (Table 35).

For ‘Recreation potential’, 10,5% of ponds have a park within a 500 m radius and are coloured red, representing recreation service supply. The demand for blue-green space for recreation through mean population density is the highest in a hotspot in the southern central part of the city, where ponds have relatively higher population densities in their 500 m radius. In the two highest priority/potential categories (0.8–1), 1.1% of ponds have a mean population

density of 198–242 people per hectare (Table 38). Almost half of the ponds (46.2%) are within 200 m of a PCA and illustrated with a red dot on the map, with only 0.6% of the ponds in the highest priority category of 2200–2400 m away from a PCA – posing constraints to multifunctionality from potentially poor stormwater quality (Table 39). Of the ponds, 79.8% are closest to the PCAs of informal settlement and industrial land cover (Table 40).

For ‘Enhancing biodiversity’, 79% of the ponds were classified as ‘Other Ecological Support Areas’ with a score of 0.25 and illustrated with light orange (Table 42). These ponds are thus lower ranking artificial wetlands and lowest ranking natural or semi-natural wetlands. Only 0.9% of the ponds were in the highest potential category and classified as ‘Critical Biodiversity Area 1’ as very high ranking ‘natural or semi-natural’ wetlands (and estuaries).

8.10 Synergies and trade-offs

Synergy and trade-off patterns were assessed after the ponds had been scored and mapped for the individual criteria. This was done by calculating Pearson correlation coefficients between criterion scores (Figure 65). Using correlations to consider positive and negative interactions between stormwater pond benefits assists with promoting multifunctionality for WSC planning and is widely used in the ecosystem services literature (Bennett *et al.*, 2009; Raudsepp-Hearne *et al.*, 2010; Turner *et al.*, 2014; Meerow & Newell, 2017).

All the estimated correlation coefficients were statistically significant at 5%, with the exception of the following four pairs: ‘Heritage’ and ‘MAR potential’, ‘Biodiversity’ and ‘UHI mitigation’, ‘Biodiversity’ and ‘Community services’ and ‘Biodiversity’ and ‘Heritage’. A positive correlation indicated a synergy between the benefits or functions, and a negative correlation indicated a trade-off between the benefits or functions. The strongest positive correlations were between ‘Recreation potential’ and ‘MAR potential’, ‘UHI mitigation’ and ‘Community services’, followed by ‘UHI mitigation’ and ‘MAR potential’.

‘Stormwater quality’ had the strongest negative correlations with ‘MAR potential’, ‘UHI mitigation’ and ‘Recreation potential’. There were predominantly negative correlations between ‘Stormwater quality’ and other criteria. The ‘Heritage’ criterion had primarily weak negative correlations with other criteria, except for a positive correlation with ‘Stormwater quality’.

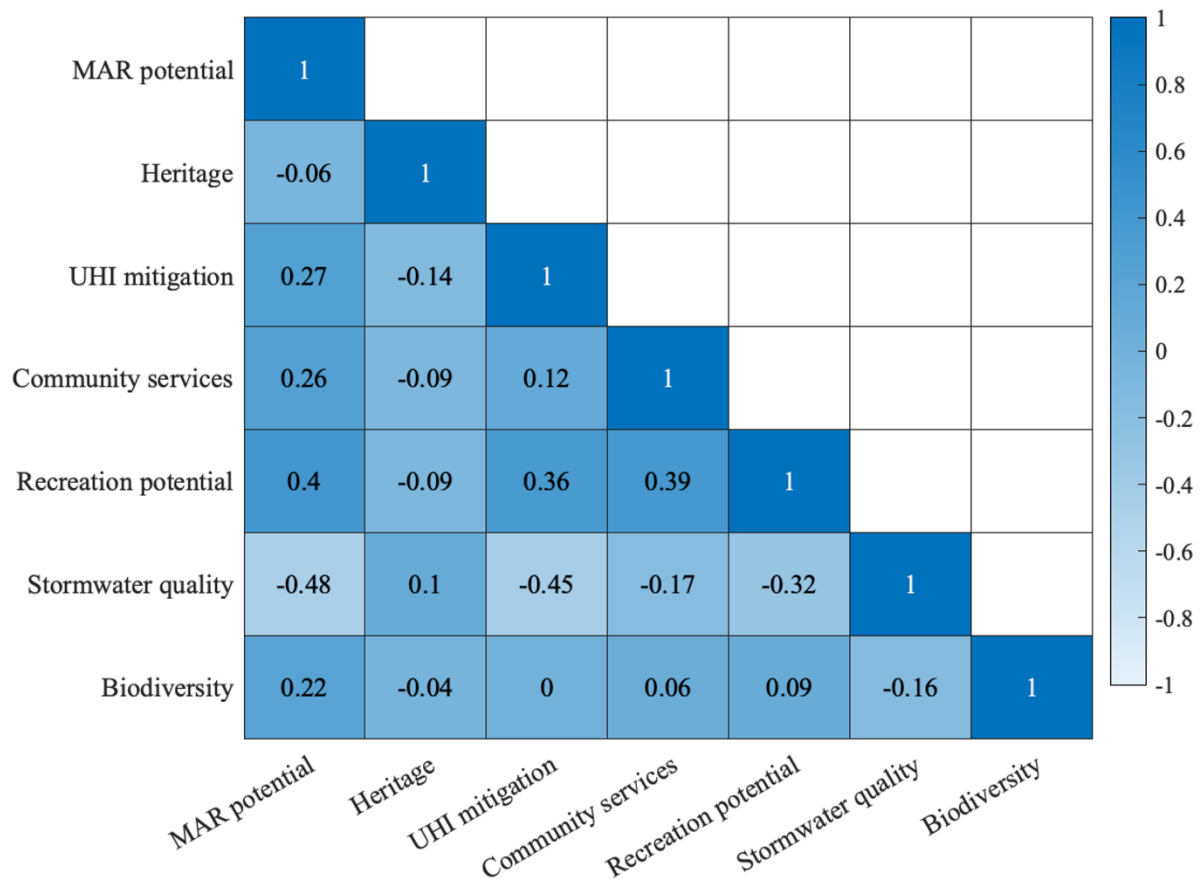


Figure 65: Trade-offs and synergies between the seven criteria

9. Weighting, combination and discussion

This chapter describes the process of obtaining and calculating stakeholder derived weights and the combination of scores and weights to provide rankings for the final MCA. It ends with a discussion of the results from the final MCA and insights from the process of developing the MCA methodology, including a comparison of the pilot MCA and final MCA.

9.1 Stakeholder derived weighting

The stakeholder derived weighting was obtained after scoring and producing individual maps for the seven criteria in Chapter 8. The seven WSC planning priorities with their associated criteria were weighted by 19 stakeholders engaged in work on WSCs, BGI and resilience at a workshop session on 21 June 2022. The stakeholder positions and affiliations are listed in Appendix H. The workshop session was part of a workshop for the ‘Pathways to water resilient South African cities’ project for the ‘Phase 1 project reflection and Phase 2 planning’. The stakeholders came from local government, academia, engineering consultancies, and community groups. The stakeholder weighting provided a key way for the judgements and value considerations of different stakeholders to be incorporated, in addition to the stakeholder input provided through the semi-structured interviews.

During the workshop session, the stakeholders were given an overview of the research and introduced to the seven WSC planning priorities and their associated criteria, as well as the weighting activities (Appendix H). Stakeholders were then given a survey to complete that included the weighting activities, as well as supplementary material to further contextualise the activity. Stakeholders weighted the seven WSC planning priorities based on which benefits or functionalities they valued the most for a WSC, in relation to multifunctional stormwater ponds, using the (1) ranking method – ranking the planning priorities in terms of importance from one (most important) to seven (least important) (Malczewski & Rinner, 2015), (2) point allocation method – allocating 100 points amongst the WSC planning priorities, with the more points a criterion receives, the greater its relative importance (ODU, 2019), and (3) pairwise comparisons method – comparing the relative importance of 21 pairs of criteria with the underlying scale from one (equal importance) to nine (extremely more important) to rate preferences using a standard Analytical Hierarchy Process approach (Saaty, 1980). Malczewski & Rinner (2015) recommend using more than one weighting method for stakeholders. The weightings from the ranking method were calculated using the rank sum method (Equation 2) (Malczewski & Rinner, 2015). The pairwise comparisons weightings were calculated using a Microsoft Excel based AHP calculator developed by Goepel (2013) and used by Meerow & Newell (2017) and Meerow (2019).

$$w^k = \frac{n - p_k + 1}{\sum_{k=1}^n (n - p_k + 1)} \quad (2)$$

Where w_k is the k-th criterion weight, n is the number of criteria under consideration ($k=1,2,\dots,n$), and p_k is the rank position of the criterion .

9.2 Stakeholder weighting results

The stakeholder preferences for the WSC planning priorities varied depending on the weighting method. ‘Increasing access to blue-green space’ was identified as the most important priority for the ranking and pairwise comparisons methods, and ‘Increasing water re-use’ was identified as the most important priority for the point allocation method (Figure 66 and Table 43).

‘Increasing access to blue-green space’ was identified as second most important for the point allocation method. However, it was only slightly less important than the highest ranked priority in view of the mean point allocation. ‘Enhancing biodiversity’ was second most important for two weighting methods. The two highest calculated weights were of 0.21 and 0.20 for ‘Increasing access to blue-green space’ and ‘Enhancing biodiversity’ for the pairwise comparison method.

‘Increasing water re-use’ was identified as most important for the point allocation method, however, it was considered fourth most important for the other two methods. The top four ranking priorities for the point allocation method had very similar weights and mean point allocations. ODU (2019) cautions that the point allocation method becomes more limited with less precision when there are six or more criteria.

‘Incorporating stormwater quality limitations’ was regarded as third most important for the pairwise comparison method, with a weighting of 0.19. This weighting was same as the top weighting for the ranking method, and higher than the top weighting of 0.17 for the point allocation method. ‘Incorporating stormwater quality limitations’ was identified as the fifth most important function for the ranking and point allocation methods. The sixth and seventh ranked priorities were the same across the three methods, with ‘Enhancing cultural and heritage associations with water systems’ in sixth and ‘Reducing the UHI effect’ in seventh.

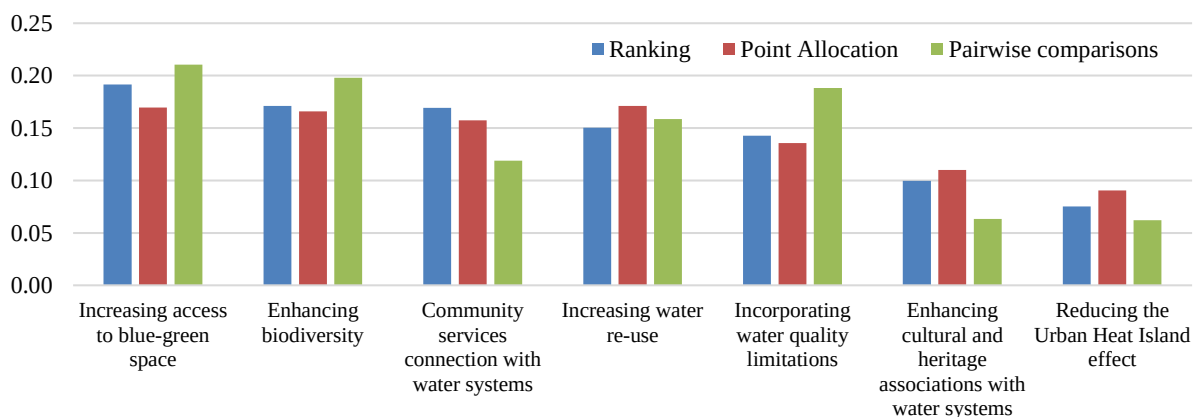


Figure 66: Stakeholder derived weighting results for the three weighting methods

Table 43: Weighting results for the three weighting methods

	Increasing access to blue-green space	Enhancing biodiversity	Enhancing community services connection with water systems	Increasing water re-use	Incorporating stormwater quality limitations	Enhancing cultural and heritage associations with water systems	Reducing the UHI effect
<i>Ranking</i>							
Order	1	2	3	4	5	6	7
Mean ranking	2.63	3.21	3.26	3.79	4.00	5.21	5.89
Standard deviation	1.46	1.652	1.76	1.96	2.16	1.69	1.33
Weighting	0.19	0.17	0.17	0.15	0.14	0.10	0.08
<i>Point allocation</i>							
Order	2	3	4	1	5	6	7
Mean point allocation	16.95	16.58	15.74	17.11	13.58	11.00	9.05
Standard deviation	6.53	7.83	7.17	10.58	7.49	6.16	3.99
Weighting	0.17	0.17	0.16	0.17	0.14	0.11	0.09
<i>Pairwise comparisons</i>							
Order	1	2	5	4	3	6	7
Weighting	0.21	0.20	0.12	0.16	0.19	0.06	0.06

9.3 Combining scores and weights

The three sets of stakeholder derived weights, along with an equal weighting scenario, were used to combine the seven criteria using Equation 1 from the weighted additive model in Microsoft Excel – producing four sets of stormwater pond multifunctional potential rankings.

Table 44 shows the distribution of the scores and the associated pond presence percentage for each weighting method. Figure 67 shows their spatial distribution in the study area. These scores show the potential of the ponds to provide a combination of the seven benefits, revealing a range of low to moderate priority ponds for multifunctional transformation. The ponds with the highest potential have scores in the 0.6–0.7 category, and are highlighted in green on Table 44, with the pond presence percentage for the four weighting methods ranging from 0.2% to 1.3%. The high multifunctional potential ponds change slightly based on the weighting methods, with a cluster of the highest scoring ponds in the in the southern central part of the city. These ponds would be the highest priority for multifunctional transformation. The different weighting methods show varying levels of potential in terms of the categories. For example, 42.1% of the

ponds for the pairwise comparison method are in the 0.2–0.3 category while 39.5% of the ponds for the rating method are in the 0.3–0.4 category. The majority of the ponds reveal a below-moderate potential to provide multifunctional benefits, being concentrated in the 0.2–0.4 categories. This means that they have potential to provide some of the benefits over others, but do not show a high potential to provide multiple benefits.

Table 44: The combined stormwater pond scores across the four weighting methods

Scores	Potential/ priority	Pond percentage			
		Equal weights	Stakeholder ranking weights	Stakeholder point allocation weights	Stakeholder pairwise comparison weights
0–0.1	Low	0%	0%	0%	0%
0.1–0.2		1.8%	3.7%	4.0%	8.4%
0.2–0.3		30.8%	30.1%	29.7%	42.1%
0.3–0.4		37.5%	39.5%	37.1%	32.0%
0.4–0.5	Moderate	23.9%	20.9%	22.5%	14.5%
0.5–0.6	Moderate	5.0%	4.6%	5.3%	2.8%
0.6–0.7		1.1%	1.3%	1.3%	0.2%
0.7–0.8		0%	0%	0%	0%
0.8–0.9		0%	0%	0%	0%
0.9–1	High	0%	0%	0%	0%

Descriptive statistics are presented in Table 45. Table 46 shows top three highest ranked ponds and their associated scores across the four weighting methods. Pond ID 301 is the top ranked pond across all the weightings. The middle and bottom ranked ponds across the four weightings methods also have similarities.

Table 45: Descriptive statistics for the pond scores

	Pond scores			
	Equal weights	Stakeholder ranking weights	Stakeholder point allocation weights	Stakeholder pairwise comparison weights
Minimum	0.148	0.147	0.149	0.110
Median	0.340	0.336	0.337	0.298
Mean	0.353	0.347	0.350	0.312
Maximum	0.691	0.680	0.688	0.619

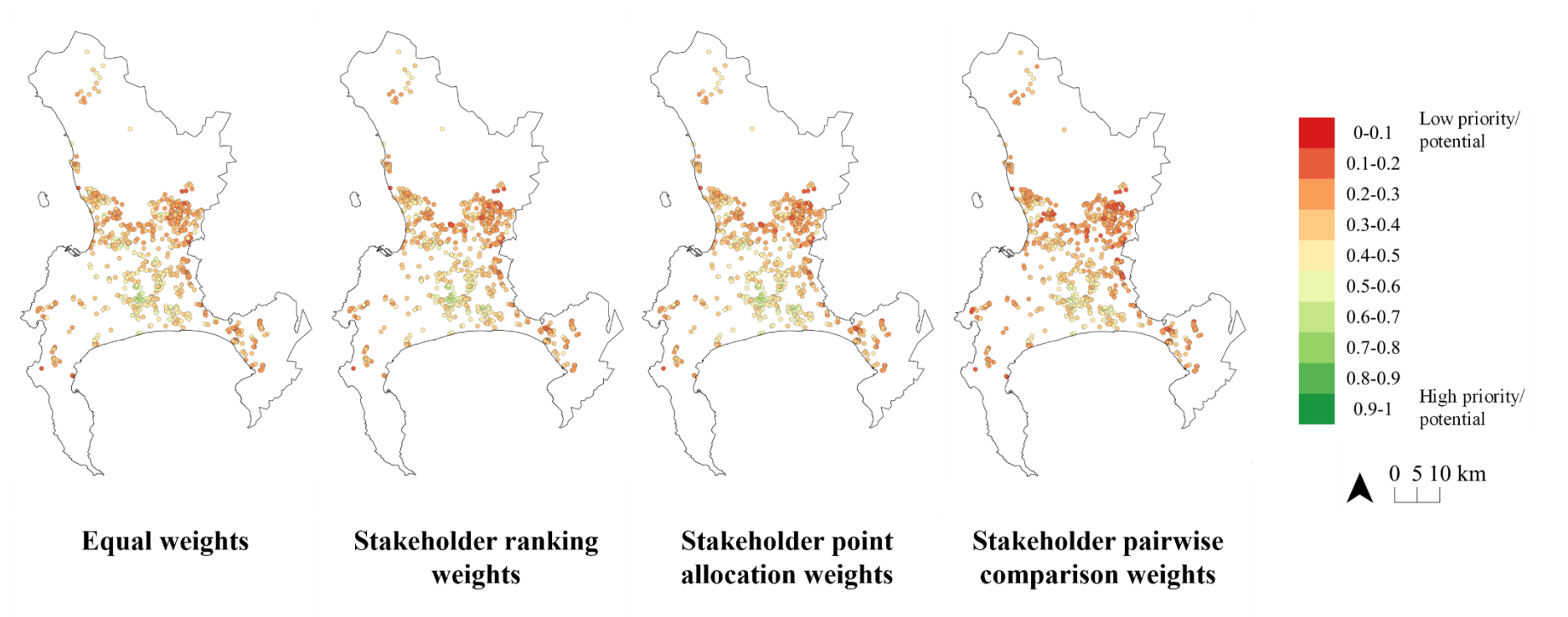


Figure 67: Combined criteria using four weighting methods showing low to high potential or priority for multifunctionality

Table 46: The top three highest-, middle two-, and last two- ranked ponds

Order	Equal weights		Stakeholder ranking weights		Stakeholder point allocation weights		Stakeholder pairwise comparisons weights	
	Pond ID	Score	Pond ID	Score	Pond ID	Score	Pond ID	Score
1	301	0.691	301	0.680	301	0.688	301	0.619
2	298	0.671	298	0.655	298	0.665	21323	0.615
3	306	0.667	306	0.652	306	0.660	298	0.589
424	898	0.340	118	0.336	765	0.337	246	0.299
425	118	0.339	650	0.335	871	0.337	650	0.298
847	27324	0.174	39329	0.155	142	0.154	507	0.119
848	142	0.148	27324	0.147	27324	0.149	27324	0.110

The top two highest ranked ponds across the three weighting methods are ID 301, 298 and 21323. Two of these ponds (ID 301 and 298) have existing sports facilities and already display a degree of multifunctionality (Figure 68), confirming that the MCA methodology correctly identifies ponds that have previously been identified as candidates for multifunctionality by others.

The individual criterion scores (Chapter 8) for the top seven highest ranked ponds across all four weighting methods are presented in Table 47 with their location shown in Figure 69. The ponds show similar potential (criterion scores) for the functions: ‘Enhancing cultural and heritage associations with water systems’, ‘Increasing water re-use through MAR’, ‘Reducing the UHI effect’ (all ponds scored 0.75) and ‘Incorporating stormwater quality limitations’. Interestingly, the top seven ranked ponds show low potential for ‘Incorporating stormwater quality limitations’, meaning they are all near a PCA. They also show low potential for ‘Enhancing biodiversity’, which was highly regarded by stakeholders during the weighting, coming out as second and third most important (Table 43). These top seven ponds are located in two clusters in the south-eastern central part of the city, near both formal and informal residential housing.

Table 47: The individual criterion scores for the top seven highest ranked ponds

Pond ID	Heritage	MAR potential	Reducing UHI	Community services	Recreation potential	Stormwater quality	Biodiversity
301	1	0.915	0.75	0.977	0.893	0.054	0.25
298	1	0.915	0.75	0.989	0.790	0	0.25
306	1	0.915	0.75	0.981	0.957	0.063	0
300	1	0.915	0.75	0.974	0.625	0	0.25
26	1	0.788	0.75	0.931	0.772	0	0.25
21323	0	0.915	0.75	0.958	0.999	0	0.50
21324	0	0.915	0.75	0.961	0.869	0	0.50

**Pond ID
301**



**Pond ID
298**



**Pond ID
21323**



Figure 68: The top two highest ranked ponds across the weighting methods

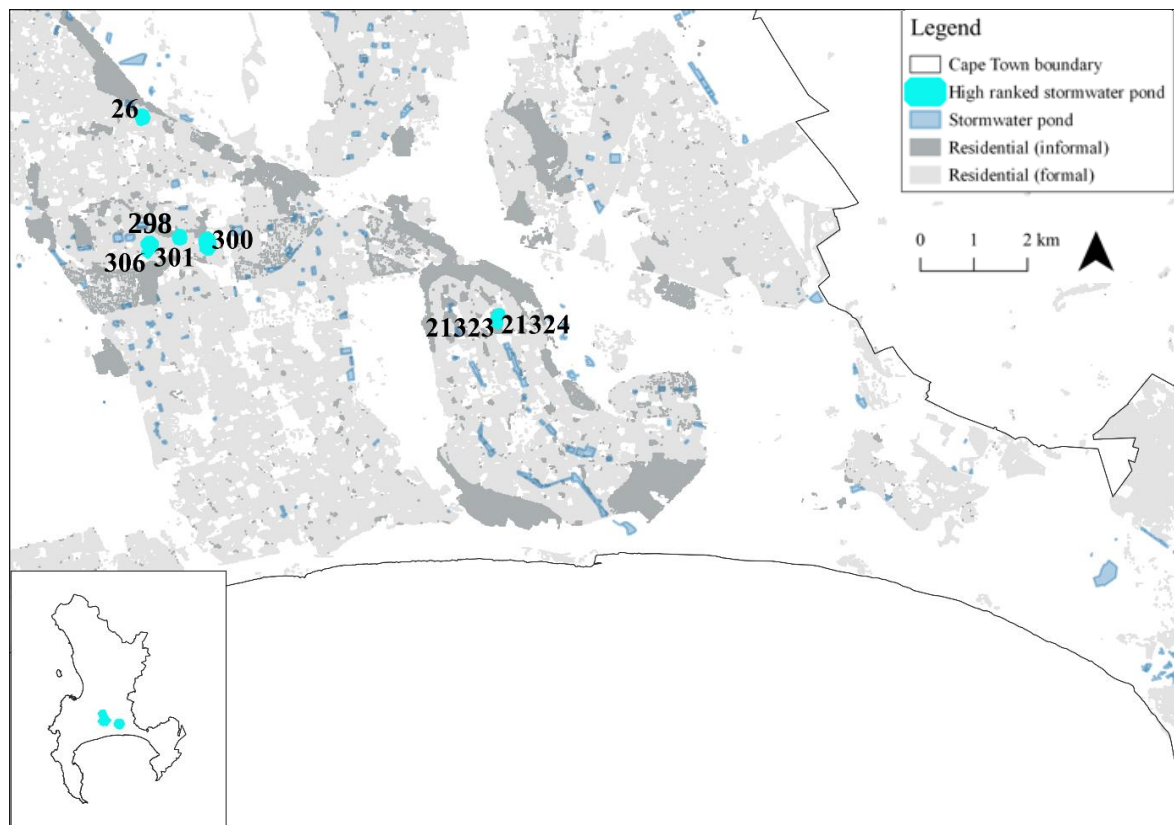


Figure 69: The top seven highest ranked ponds in Cape Town

9.4 Discussion: The stormwater ponds' multifunctional potential

The multifunctional potential rankings from the final MCA showed the relative potential for ponds to serve as BGI for a WSC, with GIS visual capabilities demonstrating the range of low to high potential for benefits across Cape Town. There appears to be missed opportunities for multifunctional benefits in some stormwater ponds.

The results illustrated that drainage perspective of stormwater ponds can be expanded, with the MCA revealing where the potential lies for multiple benefits to be provided (Ashley *et al.*, 2017). The seven WSC planning priorities and criteria served as a broadening of the vision of what existing BI can provide in a city – with value creation through the benefits. The criteria reflect various enablers, barriers and stumbling blocks for the use of existing stormwater ponds as BGI in a WSC in an urban Global South context.

The semi-structured interviews, criteria and weightings highlighted contextual issues for WSC and BGI implementation in Cape Town, with the need for demonstrated multifunctionality being high (Armitage *et al.*, 2014). Multifunctionality is needed not only to provide resilience, sustainability and liveability benefits but to address key issues of water quality and land invasions for informal housing. These are key issues facing the CCT and other municipalities in Global South contexts (Scheba *et al.*, 2021). Pursuing BGI and the goal of a WSC in the Global South

needs to incorporate a consideration of contextual issues, with local stakeholder input. This research revealed the importance of considering housing issues and pollution for Global South cities.

The semi-structured interviews as well as the pond dataset refinement indicated the problem posed by pond invasions for informal housing. Seven ponds were removed from the ponds dataset as they had been invaded by an informal settlement (Section 5.4). Furthermore, a number of respondents during the semi-structured interviews noted that ponds are already serving as multifunctional spaces, with land invasions being one of the key functions. Informal settlements present challenges that need to be addressed for a WSC transition, with comprehensive policies involving aspects such as housing, sanitation, education, health and job creation, among others.

In a city facing challenges of informal housing invasions, service delivery and competition for space, multifunctionality becomes a necessity. Multifunctionality is an important concept to safeguard the critical functioning of stormwater systems, provide resilience and liveability benefits, and to indicate the value add of ponds to discourage housing invasions. This starts to address the implementation of BGI for a WSC in a context specific manner. A WSC transition in the Global South will indeed fail if context specific realities are not identified and incorporated in a strategic manner during planning (Kumar *et al.*, 2023).

The individual criterion scores and maps indicated where high potential ponds or hotspots are, particularly if a specific benefit is being prioritised for a WSC. For example, the CCT is diversifying its water supply towards a WSC, and the ‘MAR potential’ function shows which ponds could be focused on to enhance infiltration (City of Cape Town, 2020b). The evaluation showed that there was a hotspot for MAR over the southern central part of the city. This was not surprising as these ponds overlie the unconfined sandy Cape Flats aquifer, offering suitable conditions for MAR via surface infiltration (Mauck & Winter, 2021).

The ‘Community services connection’ criterion revealed the most ponds with the highest potential for any of the benefits, with multiple hotspots across the city. A significant number of the ponds were situated close to a school, community centre or religious institution. ‘Incorporating stormwater quality limitations’ through the ‘Pond proximity to PCAs’ criterion revealed the constraints that PCAs could pose on multifunctionality at the ponds. It indicated that numerous ponds were close to an informal settlement, industrial land cover, transport routes, landfill or WWTWs. This highlights the importance of catchment management with interventions such as arborisation, rain gardens, bioretention cells and green roofs potentially contributing to addressing PCAs (Hamlyn-Harris *et al.*, 2018). Such interventions could also contribute to the provision of other benefits such as ‘Reducing the UHI effect’ and ‘Enhancing biodiversity’.

The individual criterion maps revealed potential trade-offs spatially as well as through the negative correlations. Negative correlations were statistically significant between ‘Pond proximity to PCAs’ and ‘MAR potential’. Therefore, prioritising ponds for increasing water re-

use for resilience through MAR may not be well suited to incorporate stormwater quality limitations. That is, the ponds with high MAR potential would be in close proximity to PCAs which could pose constraints on the MAR function. This is concerning as MAR via surface infiltration requires good water quality to prevent aquifer contamination (Hamlyn-Harris *et al.*, 2018). Should MAR be pursued at these ponds, planning processes would need to incorporate stormwater quality improvement interventions, not only around the stormwater ponds but at a broader catchment scale.

‘Pond proximity to PCAs’ was also negatively correlated with ‘Recreation potential’. This means that ponds that are prioritised for recreation would be in close proximity to PCAs, which could pose public health risks, indicating a valuable insight. Meerow & Newell (2017) note that *‘spatial tradeoffs reveal that multifunctionality across all benefits can be an elusive goal and underscores the fact that planning for green infrastructure is a contested and political process, in which tradeoffs have to be understood and negotiated’*. For WSC planning in Cape Town, the potential trade-offs need to be considered by multidisciplinary planning teams at an early stage to integrate all desired benefits of BGI (Carden & Fell, 2021).

Synergies between ‘MAR potential’ and ‘UHI mitigation’, ‘Community services connection’ and ‘Enhancing biodiversity’ were indicated through statistically significant positive correlations. Thus, if ‘Increasing water re-use’ through MAR is prioritised, ponds will also have a higher potential to mitigate the UHI, provide a community services connection and enhance biodiversity. Ponds with a high potential for ‘Community services connection’ were also ones with a high ‘Recreation potential’. ‘Recreation potential’ and ‘Community services connection’ with schools, religious institutions and community centres appeared to be co-located. Ponds prioritised for high ‘Recreation potential’, because of higher population densities within walking distance, will thus be also able to serve nearby schools, religious institutions and community centres. ‘Recreation potential’ was also positively correlated with ‘UHI mitigation’, which was not surprising as developing recreation spaces with increased greening would contribute to UHI mitigation (Wong *et al.*, 2021). The synergies serve as planning support, providing added incentives to prioritise benefits like MAR, as there is high potential for three other benefits to be provided simultaneously. Synergistic patterns can increase the viability of BGI as part of a WSC (Turner *et al.*, 2014). This reflects expert stakeholder feedback that multifunctionality can form an economic argument for a city like Cape Town as it develops BGI (City of Cape Town, 2019).

Stakeholder weighting revealed that the most important benefit identified by Cape Town stakeholders was ‘Increasing access to blue-green space’ for two weighting methods and ‘Increasing water re-use’ for one weighting method. ‘Enhancing biodiversity’, ‘Community services connection’ and ‘Incorporating stormwater quality limitations’ were identified as the next most important benefits for a WSC in relation to multifunctional stormwater ponds. ‘Enhancing cultural and heritage associations with water systems’ and ‘Reducing the UHI effect’ were the lowest ranked criteria across the three methods. These weightings provided an opportunity for stakeholder participation in WSC planning, revealing the relative value that stakeholders place on different benefits and functions for BGI. Planning and decision making for

goals such as water sensitivity and resilience in a city is unavoidably political and requires a collaborative process using various stakeholder priorities (Meerow & Newell, 2019).

Combining the seven criteria using a weighted additive model, and stakeholder derived weighting along with an equal weighted scenario, revealed low to above moderate priority ponds for providing a combination of the seven benefits. The highest relative multifunctional potential ponds changed slightly based on the weighting methods. Ponds with the highest relative multifunctional potential appeared to be located in a small cluster in the southern central part of the city. These ponds would be the highest priority for multifunctional transforming to maximise benefits as BGI for a WSC. The relative priorities and their visual representation on the maps, serve as planning support for strategic decision making about BGI implementation. The ponds that do not have multi-functional potential for providing a combination of the seven benefits have to be maintained for the function of flood management only.

The highest scoring ponds in the above moderate potential category only constituted 0.2% to 1.3% of the ponds depending on the weighting method. This information serves to offer more realistic expectations of the implementation potential and related benefit provision of BGI (Aleksejeva *et al.*, 2022). Whilst the highest scoring ponds only constitute a small proportion of the ponds, ponds in the moderate category still offer potential for benefit provision and can be strategically targeted to address city specific needs. Widescale implementation of BGI for a WSC is often cited as a policy goal but there are practical limitations to this. Thus, the approach developed in this research could assist with municipal planning processes for targeted and practical BGI interventions. The provision of combination of seven benefits simultaneously may also present practical and limitations that need to be considered during city planning.

The top seven highest ranked ponds for multifunctionality potential are in the south-eastern central part of the city. They are located in an area with built up residential formal and informal land cover. This spatial context and the associated socio-economic realities would need to be taken into account and negotiated during a further planning process. Attention would need to be given to contextual issues of equity, employment, water quality and land invasions. The vision and manifestation of a WSC is context specific, and planning needs to account for these kinds of realities (Brown *et al.*, 2016).

The MCA used seven criteria to produce the stormwater pond multifunctional potential rankings, however the MCA is flexible enough to use with a smaller number of criteria to target particular benefits. Furthermore, the individual criterion scores for the highest priority ponds can be used to target and develop benefits at ponds, following more detailed site scale assessments. For example, the highest ranked pond across the four weighting methods revealed high potential for ‘Enhancing cultural and heritage associations with water systems’, ‘Increasing water re-use’ through ‘MAR potential’ and providing ‘Community services connection’, with slightly lower potential for ‘UHI mitigation’ and ‘Recreation potential’. ‘Pond proximity to PCAs’ revealed important stormwater quality limitations at the ponds to be included at a planning stage and a low-moderate potential to for ‘Enhancing biodiversity’. The true expression of BGI is as an integrated part of the urban fabric with feedbacks between the system. The location of the pond

(the biophysical, socio-economic and governance context) will impact its functioning as BGI and the pond will also affect the function and quality of its surroundings (Rijke *et al.*, 2008; Lerer *et al.*, 2015; Kuller *et al.*, 2017).

The synergies and trade-offs and overall scores and maps need to be engaged with to strengthen WSC planning processes using stormwater ponds as BGI with an understanding of the implications for resource use and equity (Kremer *et al.*, 2016). The MCA provides a process to assist with ensuring multiple benefits can be provided in areas where there is high potential. Decision making using the MCA needs to consider various nuances, for example, the CCT may adopt a more regionalised approach focusing on a narrower number of benefits based on physical and urban characteristics, and using the synergies and trade-offs to support the process. The MCA provided a means to illuminate and evaluate context specific benefits, functions and realities to plan and make decisions for a WSC using stormwater ponds, that would be overlooked in the absence of such an evaluation. Such information is not available in a strategic and structured form at a city scale for Cape Town.

The individual and combined criteria maps provided targeted visual planning support for stakeholders to engage with, to assist WSC planning. This support can be enhanced through presenting the results in a digestible manner on publicly accessible websites, with this research creating an accompanying Esri Storymap for this purpose (<https://arcg.is/XuGHD>) (Fell, 2022). The StoryMap creates awareness of the opportunity presented by existing BI such as stormwater ponds to provide multiple benefit for a WSC.

The MCA provides a strategic, flexible, participatory and transferable way to evaluate existing BI to provide multiple benefits for a WSC. These diverse benefits underscore the need for multiple disciplines and sectors to be involved as key stakeholders in WSC planning for BGI. The MCA provides a process and framework to unite stakeholders and break down silos. This planning supports the ‘*interplay between technical systems, socio-political contexts, professional praxes and biophysical realities*’ needed to realise the full benefits of BGI in a WSC (Fryd *et al.*, 2012).

9.5 Insights from developing the multi-criteria analysis methodology

This research developed a strategic, flexible, participatory and transferable MCA methodology to evaluate the potential for existing BI to provide multiple benefits as BGI for a WSC. The MCA methodology was developed with the key steps of an MCA (Section 2.9), through the case study context of Cape Town. This process of developing the MCA for Cape Town’s stormwater ponds (Figure 20) revealed various insights, which are discussed in this section.

An informative step in this research was conducting the pilot MCA, which was used to develop the final MCA for Cape Town’s stormwater ponds and inform the MCA methodology. The pilot MCA used pre-processed and publicly available datasets, literature and the author’s

judgement, with no stakeholder input. The final MCA used stakeholder input for multiple key stages through the semi-structured interviews (Chapter 7) and the stakeholder derived weightings (Section 9.1 and 9.2). Table 48 shows the WSC planning priorities and associated criteria used for the pilot MCA (Chapter 6) and the final MCA. The pilot MCA used five WSC planning priorities, each with an associated criterion. The final MCA used seven WSC planning priorities, each with an associated criterion.

The pilot MCA was used as a basis to refine the WSC planning priorities, criteria, datasets and scoring for the final MCA. Thus, while there were similarities between the criteria and scoring used, none were the same. For example, the ‘Enhancing cultural and heritage associations with water systems’ WSC planning priority used the same criterion from the pilot MCA but included additional culture and heritage datasets in the final MCA (Section 6.2 and Section 8.2). For ‘Increasing access to blue-green space’, the pilot MCA criterion was expanded on to develop the ‘Recreation potential’ criterion for the final MCA. The final MCA used the ‘Mean population density in 500 m pond radius’ criterion from the pilot MCA with an additional indicator of ‘Park presence’ (Section 6.4 and Section 8.6). For ‘Incorporating stormwater quality limitations’, the criterion from the pilot MCA was similarly expanded on by including additional land covers to ‘informal settlement’ for the final MCA (Section 6.5 and Section 8.7). For ‘Increasing water re-use’, the final MCA used the same four indicators as the pilot MCA, however, the indicator of ‘Surficial geology’ was used as a mask layer, and some different datasets and indicator performance scoring were used (Section 6.3, Appendix E and Section 8.3).

Table 49 shows a comparison of the combined stormwater pond scores for the pilot MCA and for the final MCA. There are differences between the distribution of scores from the pilot MCA to the final MCA. However, these differences are not that significant. For example, 41.9% of the ponds in the pilot MCA are in the 0.2–0.3 score range while 42.1% of the ponds in the final MCA (with stakeholder pairwise comparison weights) are in the same range. The pilot MCA had the highest scoring ponds in the 0.7–0.8 range, while the final MCA had the highest scoring ponds in the 0.6–0.7 range. The top five highest ranked ponds from the pilot MCA and the final MCA are however different, with no ponds overlapping (Table 50). Pond ID 301, which was the highest ranked pond for the four weighting methods from the final MCA, was ranked 10th for the pilot MCA. The differences in scoring and top ranked ponds were expected given the different criteria, scoring, datasets and weightings that were used for the pilot MCA and for the final MCA.

The pilot MCA was a valuable and informative step in this research and provided familiarity with the process of an MCA. It assisted with building the strategic, flexible, participatory and transferable elements of the MCA methodology. For example, stakeholder participation through the semi-structured interviews was enhanced by using the pilot MCA results to obtain actionable input. The stakeholders that were interviewed thus had a clear understanding of the MCA and were able to provide targeted input (Chapter 7). Conducting a pilot MCA as a preliminary step could have value in future research using an MCA.

Table 48: Comparison of WSC planning priorities and associated criteria

Pilot MCA		Final MCA	
WSC planning priority	Criterion and data sources	WSC planning priority	Criterion and data sources
Enhancing cultural and heritage associations with water systems	Culture and heritage sites (City of Cape Town, 2019f).	Enhancing cultural and heritage associations with water systems	Culture and heritage sites (City of Cape Town, 2019h, 2019k).
Increasing water re-use	MAR potential (four indicators of Surficial geology, Aquifer type and presence, Soil permeability and Transmissivity (Bailey & Pitman, 2012; Wright & Jacobs, 2016; World Agroforestry Centre Landscape Portal, 2021; Atkins <i>et al.</i> , 2021).	Increasing water re-use	MAR Potential (four indicators of Surficial geology (mask layer), Aquifer, Soil permeability and Transmissivity (Bailey & Pitman, 2012; Wright & Jacobs, 2016; World Agroforestry Centre Landscape Portal, 2021; City of Cape Town, n.d.-c).
Increasing access to blue-green space	Mean population density in 500 m pond radius (Statistics South Africa, 2011).	Increasing access to blue-green space	Recreation potential (two indicators of park presence and mean population density in 500 m pond radius (Statistics South Africa, 2011; City of Cape Town, 2019i)).
Incorporating stormwater quality limitations	Proximity to informal settlement (Department of Forestry Fisheries and the Environment, 2021).	Incorporating stormwater quality limitations	Proximity to PCA (informal settlement, industrial, roads, landfill, wastewater treatment works,) (City of Cape Town, 2019g, 2019m; Department of Forestry Fisheries and the Environment, 2021).
Enhancing biodiversity	Terrestrial Biodiversity Network category (City of Cape Town, 2019n).	Enhancing biodiversity	Aquatic biodiversity category (Snaddon & Day, 2009).
		Reducing the UHI effect	UHI intensity risk (land cover classes, daily normalised, irradiation and windspeed) (Petrie <i>et al.</i> , 2019).
		Enhancing community services connection with water systems	Proximity to schools, community centres and religious institutions (City of Cape Town, 2019e, 2019j; Department of Basic Education, 2021).

This research included stakeholder participation for the key MCA steps of criteria selection and weighting. Furthermore, the objectives and scoring were informed, in part, by stakeholder participation. The semi-structured interviews with seven WSC experts were a critical component of the research (Chapter 7). They added value by providing numerous contextual realities and perspectives on multifunctionality, WSCs, BGI and stormwater ponds. Table 24 shows the WSC planning priorities and proposed criteria pre- and post- the interviews. It reflects the value of expert stakeholder input, showing how the WSC planning priorities and proposed criteria were refined. Stakeholder derived weighting was another key participatory element and a way for different judgements and value considerations to be incorporated. The research showed that incorporating stakeholder input and preferences through expert semi-structured interviews and stakeholder weighting can enhance a participatory MCA approach to WSC planning. This stakeholder input strengthened the quality, transparency and legitimacy of the final MCA (Dean, 2018).

The city scale of the research and the number of stormwater ponds (800+) require the results to be presented in a visual and intuitive format. The maps produced in GIS for the individual and combined criteria, showing the spatial distribution of the scores (Figures 64 and 67), add value to the planning support of the MCA. These maps provide a visual representation of the multifunctional potential of the stormwater ponds, with colour coding used to enhance the interpretation of the results. This strengthens the planning support and its appeal as a transferable MCA methodology for evaluating other types of BI.

Table 49: Comparison of the combined stormwater pond scores

Scores	Potential/ priority	Pond percentage				
		Pilot MCA	Final MCA			
		Weights	Equal weights	Stakeholder ranking weights	Stakeholder point allocation weights	Stakeholder pairwise comparison weights
0–0.1	Low	0%	0%	0%	0%	0%
0.1–0.2		1.9%	1.8%	3.7%	4.0%	8.4%
0.2–0.3		41.9%	30.8%	30.1%	29.7%	42.1%
0.3–0.4		40.6%	37.5%	39.5%	37.1%	32.0%
0.4–0.5	Moderate	9.1%	23.9%	20.9%	22.5%	14.5%
0.5–0.6	Moderate	4.7%	5.0%	4.6%	5.3%	2.8%
0.6–0.7		1.5%	1.1%	1.3%	1.3%	0.2%
0.7–0.8		0.4%	0%	0%	0%	0%
0.8–0.9		0%	0%	0%	0%	0%
0.9–1	High	0%	0%	0%	0%	0%

Table 50: A comparison of the top five highest ranked ponds

Order	Pilot MCA		Final MCA							
	Weights		Equal weights		Stakeholder ranking weights		Stakeholder point allocation weights		Stakeholder pairwise comparison weights	
	Pond ID	Score	Pond ID	Score	Pond ID	Score	Pond ID	Score	Pond ID	Score
1	127	0.758	301	0.691	301	0.680	301	0.688	301	0.619
2	4923	0.749	298	0.671	298	0.655	298	0.665	21323	0.615
3	4924	0.749	306	0.667	306	0.652	306	0.660	298	0.589
4	321	0.681	300	0.645	21323	0.633	300	0.635	21324	0.588
5	275	0.642	26	0.641	26	0.623	26	0.631	306	0.585

The MCA methodology was developed to be strategic, flexible, participatory and transferable in nature. Table 51 shows these elements that were developed during the process.

Table 51: The strategic, flexible, participatory and transferable MCA elements

MCA elements	Description
Strategic	Value-focused thinking is used to identify and structure objectives (Section 3.4) in accordance with the vision of a WSC (Section 2.2).
Flexible	The seven WSC planning priorities (objectives) and criteria can be adapted. Different existing BI options can be used. The steps and process of the MCA can be adapted.
Participatory	Stakeholder input is obtained through expert semi-structured interviews and stakeholder weighting.
Transferable	The MCA methodology can be used for other contexts, and particularly in the Global South.

10. Conclusions and recommendations

This study aimed to develop an MCA to evaluate the potential for existing BI to provide multiple benefits as BGI. This was done through the case study of existing stormwater ponds in Cape Town, as part of its commitment to become a WSC. The five research questions (Section 1.2) were structured around an MCA and addressed in the research:

- How can value-focused thinking be used to identify BGI and WSC benefits to be used as MCA objectives? Value-focused thinking was used to identify and structure seven WSC planning priorities which were used as MCA objectives.
- What relevant contextual criteria may be used to measure the achievement of these objectives? Seven criteria were selected and used to measure the achievement of the MCA objectives (Chapter 8).
- What are the synergies and trade-offs between different benefits? Synergies between ‘MAR potential’ and ‘UHI mitigation’, ‘Community services connection’ and ‘Enhancing biodiversity’ were indicated and trade-offs between ‘Pond proximity to PCAs’, ‘MAR potential’ and ‘Recreation potential’ were indicated.
- Can incorporating stakeholder input in a participatory MCA enhance WSC planning? Incorporating stakeholder input through semi-structured interviews and stakeholder derived weighting enhanced the WSC planning support from the MCA.
- What does the application of the MCA methodology to Cape Town’s stormwater ponds reveal about their multifunctional potential? The MCA methodology revealed low to above moderate priority ponds for providing a combination of the seven benefits, indicating missed opportunities for multifunctional benefits in some stormwater ponds in Cape Town.

The contribution to knowledge was twofold: (1) the MCA methodology developed through the case study, and (2) the outputs and insights obtained from applying the MCA methodology to existing stormwater ponds in Cape Town. These two areas of knowledge contribution are discussed in this chapter, followed by recommendations for further research.

10.1 A multi-criteria analysis methodology

This research developed an MCA methodology to evaluate the potential for existing BI to provide multiple benefits as BGI for a WSC. The MCA methodology is strategic, flexible, participatory and transferable (Table 51). It included various steps and a process that can be replicated and customised in different contexts for existing BI types. There is flexibility to either expand on the objectives and criteria in the research or develop new ones. The case study of Cape Town provided a suitable context for the development of the MCA because of its commitment to become a WSC and its typical Global South challenges. These challenges were related to water

management and planning, urbanisation patterns and resource constraints. The flexibility of the MCA allows for contextual realities and limitations to be incorporated, particularly for Global South contexts.

Seven fundamental objectives representing common benefits provided in a WSC were identified using a value-focused approach. They were framed as WSC planning priorities. This facilitated the strategic identification of what is valued in a WSC, without narrowing the process through focusing on predetermined options. The seven WSC planning priorities included: (1) ‘Enhancing cultural and heritage associations with water systems’, (2) ‘Increasing water re-use’, (3) ‘Reducing the UHI’, (4) ‘Enhancing community services connections with water systems’, (5) ‘Increasing access to blue-green space’, (6) ‘Incorporating stormwater quality limitations’, and (7) ‘Enhancing biodiversity’. These WSC planning priorities can be used as high-level strategic objectives for WSC planning in other contexts. They can also be developed further with the use of value-focused thinking.

BGI was specified as the means objective, that is, as a means to provide the fundamental WSC objectives. An adapted ‘five Ws of a WSC’ framework was used to explore WSCs and BGI for what, why, who, when and where (Table 7). It allowed the breadth of these concepts to be investigated without initial constraints posed by options and context. The adapted framework is useful to critique values and objectives in planning processes, with the framing of fundamental and means objectives (Table 6).

The Cape Town case study context shaped the rest of the MCA, providing examples for the various steps. The existing BI options that focused the evaluation in Cape Town were the multitude of existing stormwater ponds that might be transformed for multifunctionality. The pilot MCA that was conducted provided a useful means to investigate and refine the WSC planning priorities and criteria. For the final MCA, selecting criteria was guided by the pilot MCA and stakeholder input through semi-structured interviews, highlighting the critical value of participatory processes for this MCA step. The interviews were also useful to emphasise contextual realities and provide input on the performance scoring step. The types of questions asked during the interviews in this research can assist with obtaining useful input to an MCA (Table 23). For example, stakeholders guided the inclusion of different land covers for the criterion associated with the ‘Incorporating stormwater quality limitations’ planning priority. Stakeholders gave input on the strategic consideration of ponds that could contribute to MAR via surface infiltration. This guided the criterion selected to allow for a reflection of ‘MAR potential’ as well as the performance scoring.

The selected criteria and associated datasets organised under the WSC planning priorities from the final MCA were a means to measure the ponds multifunctional potential (Table 25). They can be used or adapted to measure the multifunctional potential of other types of existing BI. The proportional scoring showed a means for this measurement. For example, the ‘Community services connection’ WSC planning priority showed the importance of organisations such as schools, community centres and religious institutions in a WSC. The ‘Incorporating stormwater quality limitations’ WSC planning priority indicated the reality and

challenge of polluted stormwater and how it can hinder the success of BGI, through constraining functions from MAR to biodiversity to recreation. This showed the need to consider how poor stormwater quality may in reality be a considerable obstacle to successful BGI implementation. The criterion gave a means to consider these constraints, through assessing proximity to the land covers of informal settlement, industrial, WWTW, transport and landfills. Planning for a WSC would need to consider such PCAs strategically, either to avoid them or address them. Including informal settlements in this criterion was a means to acknowledge the complexities and contextual limitations of implementing BGI in Global South contexts (Pauleit *et al.*, 2021; Kumar *et al.*, 2023).

The evaluation was enhanced by assessing synergies and trade-offs through correlations using the individual criterion scores. This can be used for other types of existing BI. Obtaining stakeholder derived weighting strengthened the participatory elements of the MCA for WSC planning (Table 43). The three common methods of point allocation, ranking and pairwise comparison used in this research showed a means to practically incorporate stakeholder weightings. The combined scores and weights provided the multifunctional potential rankings, prioritising existing BI for multifunctional transformation. Using GIS to map the individual and combined benefit criteria provided a visual representation of the results, enhancing their value as WSC planning support. The weighted additive model presented a simple MCA method that was understandable and transparent to support WSC planning with BGI.

10.2 Evaluating existing stormwater ponds in Cape Town

The application of the MCA methodology to the focus point of existing stormwater ponds illuminated the missed opportunity presented by this BI. It provided novel insights into the relative multifunctional potential of existing stormwater ponds in Cape Town to provide seven WSC benefits both individually and combined at a city scale. This relative multifunctional potential would be overlooked in the absence of such an evaluation, and currently does not exist in this form for Cape Town. The synergy and trade-off patterns, and stakeholder preferences obtained through weighting, provided additional planning support.

The semi-structured interviews revealed insights into the Cape Town context, with the need for multifunctional infrastructure being high. Multifunctionality was identified as a way to provide resilience, sustainability and liveability benefits. Furthermore, multifunctionality emerged as a means to incorporate key issues of stormwater quality and land invasions for informal housing – key issues that the CCT and other Global South cities face when planning for a WSC.

The WSC benefit of ‘Enhancing community services connection with water systems’ had the largest number of high potential ponds. However, almost half of the ponds were within 200 m of a PCA – indicating potential constraints to multifunctionality from ‘Incorporating stormwater quality limitations’. This insight indicates the need for the CCT to develop targeted stormwater quality management programs to address PCAs. Synergies emerged between ‘MAR

potential’ and ‘UHI mitigation’, ‘Community services connection’ and ‘Enhancing biodiversity’ – this helps identify ponds for strategic prioritisation to leverage co-benefits. Trade-offs that emerged were that prioritising ponds for ‘Increasing water re-use’ and ‘Recreation potential’ may not be well suited to ‘Incorporate stormwater quality limitations’. Stakeholders regarded the benefits of ‘Increasing access to blue-green space’ and ‘Increasing water re-use’ as the most important across the weighting methods.

The combined criteria using different weighting methods indicated a hotspot of ponds with the highest relative multifunctional potential in the southern central part of the city. These ponds would be the highest priority for multifunctional retrofitting to maximise benefits as BGI for a WSC. The CCT could focus on these ponds in developing actions and allocating resources for transitioning to a WSC. The use of GIS to create a visual representation of the MCA rankings with colour coding demonstrated the value of WSC and BGI planning support in this form. An accompanying Esri Storymap enhanced the planning support (<https://arcg.is/XuGHD>) (Fell, 2022). The focus point of stormwater ponds demonstrated the potential of this type of existing BI to function as BGI for a WSC.

10.3 Recommendations for future research

- Conducting finer scale analyses and detailed suitability assessments on a subset of high priority ponds to identify appropriate designs based on land use, cost and other contextual factors for multifunctional transforming.
- Issues of equity need to be included in BGI and WSC planning. Finer scale analyses and detailed suitability assessments on a smaller subset of stormwater ponds can better incorporate the nuances of equity. Equity could be included explicitly in a number of the WSC planning priorities at a finer scale by prioritising various benefits for minority and vulnerable groups. This would need to be undertaken in a sensitive manner, particularly with regards to identifying minority and vulnerable groups and the relative ways they would be prioritised in an MCA. This would be suited to interdisciplinary research to ensure various perspectives are incorporated.
- The MCA includes seven criteria, but the approach allows for the inclusion of additional objectives and criteria. Examples of additional criteria that could be used are: cost, green job potential and safety and security (crime). Some of these additional criteria were proposed by stakeholders in the semi-structured interviews (Chapter 7).
- Refining and improving criteria by accessing higher quality datasets with spatial and temporal similarities. For example, the ‘Increasing access to blue-green space’ WSC planning priority and criterion used the 2011 South African census data, which was the most up to date available census data at the time of undertaking this research. Updated census data could be used when it becomes available to improve the criterion.

- The ‘Incorporating stormwater quality limitations’ WSC planning priority had a criterion of ‘Proximity to PCAs’ of informal settlement, industrial, transport, WWTWs and landfill land cover. This criterion could be improved by including additional land covers or activities that tend to be associated with poor stormwater quality. For example, sewer overflow data could be included. The criterion could also use the scoring the distinguish between once off high impact events versus continuous low impact land covers such as informal settlements. For example, an industrial discharge may be once off but have a significant negative impact while informal settlement discharges may be lower impact but with a continuous signal.
- The ‘Increasing water re-use’ WSC planning priority had a criterion of ‘MAR potential’. This considered storing water for re-use underground. This could be expanded on to incorporate stormwater harvesting via temporary surface storage.
- The ‘MAR potential’ for the Increasing water re-use’ WSC planning priority included four indicators. Additional indicators could be included such as ‘Depth to the water table’ and ‘Water quality’.
- Monitoring, modelling and stakeholder surveys can be conducted to refine the criteria and improve the MCA method. Furthermore, the input of local residents would enhance the MCA at an individual stormwater pond scale.
- Converting the MCA methodology developed into a programmatic format that is more useable for different stakeholders.
- Applying the MCA methodology to other types of existing BI such as river reaches, canals and wetlands. This could be done in Cape Town to contribute to the WSC commitment, or in other Global South contexts.
- Undertaking a survey to investigate other types of existing BI in Cape Town that could be transformed to contribute to the WSC commitment. This could contribute to a strategic approach to using multifunctional infrastructure for a water sensitive Cape Town.
- Consideration of other MCA techniques that are more complex and mathematically advanced (see the MCA ‘Formal Methods’ in Figure 14) than the weighted additive model used in this research. Additionally, other types of criteria weighting techniques could be used.

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Appendix A

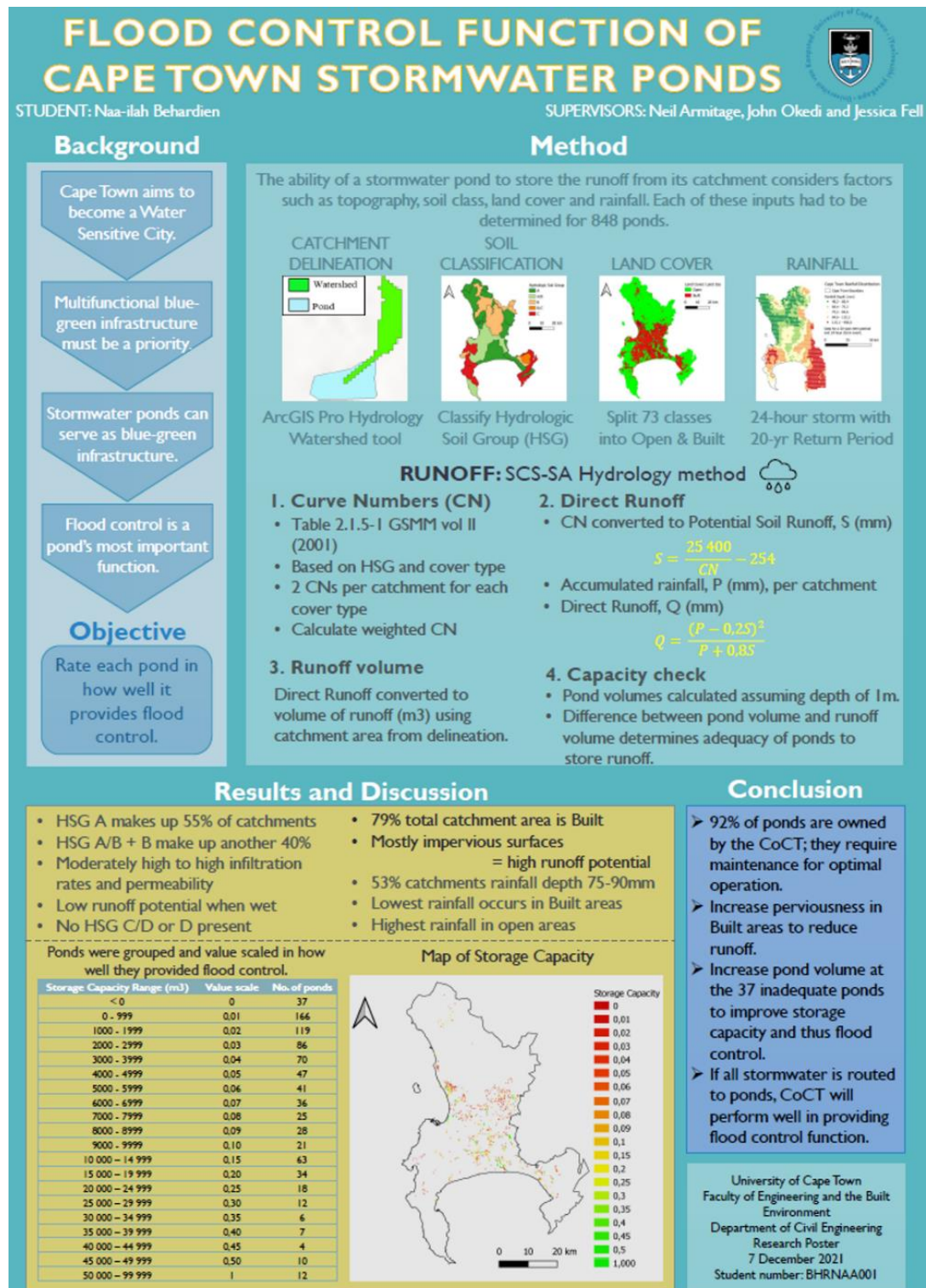


Figure A1: The Honours level BSc(Engineering) study evaluating flood control function (Behardien, 2021)

Appendix B

Semi-structured interview with CCT official in Asset Management in the Catchment, Stormwater and River Management branch in the Water and Sanitation Department on 4 June 2021.

Questions:

- Does the stormwater waterbodies shapefile from the Open Data Portal serve as the pond asset register?
- Which department made the layer?
- Of the stormwater waterbodies layer: Natural and semi-natural, Dam, Stormwater Pond, Transformed, Stormwater depression, WWTW Effluent Pond, Open Reservoir, WWTW Pond, Quarry, Irrigation Pond, Marina, what is the difference/significance between stormwater ponds and stormwater depressions and natural and semi-natural?
- Who manages what ponds and why?
- Why are there different categories, what are the operations, maintenance and management implications for the different categories?
- Do you treat retention and detention ponds differently?
- Is there a list of assets and maintenance?
- Do ponds of a certain size have a specific implication for management and maintenance?
- What would the CCT say the purpose of its stormwater ponds is?
- Are the majority of the ponds intended for one purpose only, i.e., attenuation? Are they designed to reduce to a five-year 12 hour design flood?
- Is there a list of retention versus detention?

Responses:

- The asset register is our GIS systems, the layer forms the fundamentals of the asset register, and we use it because of the spatial representation and the accompanying asset attribute data (size, depth, etc.)
- The Stormwater Waterbodies layer is owned by the environmental department who did a mapping project a while back. We (Catchment, Stormwater & River Management) use it but the environmental department manages it, you will have to get in touch with someone else for more on the history of the dataset and the governance around it.
- The accountabilities and roles and responsibilities for stormwater ponds are mixed. We are responsible for a subset of open waterbodies but some of them aren't managed assets.

- The ponds are owned by either the roads or catchment branch, the differentiation is that if the pond is associated with the bulk drainage system or a main river or if it provides a main drainage function, it is the responsibility of the catchments department.
- If the pond was put in for a local development or road drainage, then it's the roads department responsibility.
- Recently the city went through an exercise of splitting up the assets between the catchments and roads department and that has been captured on a list. Both departments stood over paper maps or PDF maps and indicated which ponds belong to which department, however this list has not been finalised yet.
- The culture in the roads department is much more around quickly getting rid of stormwater, the catchments department is more open to WSUD principles.
- Most of the ponds are likely to be the responsibility of the roads department.
- Some ponds are maintained, for instance, the lawn is mowed on dry ponds, drains are inspected, grids replaced, etc.
- The wet ponds have different maintenance requirements– remove vegetation, sediment removal, stilling base gets dirty.
- Interventions will differ. I think there is a list of operations and maintenance requirements – a spreadsheet with maintenance stuff.
- There was such a marked lack of maintenance over the last 20 years and the catchments and rivers are in terrible shape, because of this maintenance is improving as the city sees the consequences of poor maintenance.
- A lot of ponds have multiple functions, at coarsest level they have an attenuation function, but some will have biodiversity function, water treatment function. A lot of these 'multifunctional' ponds are in development sites.
- There are literally hundreds of dry ponds across the city.
- Some ponds do have a high infiltration potential so are inadvertently providing a MAR function.
- The ponds are designed for a design storm to reduce flow by certain amount over time, the original designs are sitting in the records office for each roads district.

Appendix C

Table C1 to Table C6 detail the ponds removed and edited during the data refining process in Section 5.4.

Table C1a: Duplicate ponds

Object ID	Material	Stormwater pond ID	Catchment	Pond ownership	Estimated area (m ²)
9	Unspecified	SWPO_200	Zeekoe	CCT	32181.73
10	Unspecified	SWPO_201	Zeekoe	CCT	8035.42
31	Unspecified	SWPO_659	MPlain	CCT	1812.57
32	Unspecified	SWPO_643	MPlain	CCT	10167.52
34	Unspecified	SWPO_659	Atls	CCT	2059.1
35	Unspecified	SWPO_110	Atls	CCT	1437.04
36	Unspecified	SWPO_186	Diep	CCT	7128.24
37	Unspecified	SWPO_256	Diep	CCT	1221.25
45	Unspecified	SWPO_195	Diep	CCT	2083.8
48	Unspecified	SWPO_261	Diep	CCT	8479.57
51	Unspecified	SWPO_269	Sout	CCT	2868.84
52	Unspecified	SWPO_659	Diep	CCT	25816.87
58	Unspecified	SWPO_276	Atls	CCT	3310.3
60	Unspecified	SWPO_659	Diep	CCT	2083.8
66	Unspecified	SWPO_659	Sout	CCT	744.59
67	Unspecified	SWPO_297	Sout	CCT	1076.61
68	Unspecified	SWPO_298	Sout	CCT	71.29
69	Unspecified	SWPO_299	Sout	CCT	707.06
70	Unspecified	SWPO_300	Sout	CCT	805.1
71	Unspecified	SWPO_301	Sout	CCT	3384.23
72	Unspecified	SWPO_302	Sout	CCT	1278.17
73	Unspecified	SWPO_303	Sout	CCT	71.25
74	Unspecified	SWPO_304	Sout	CCT	822.22
75	Unspecified	SWPO_305	WCoast	CCT	3392.28
77	Unspecified	SWPO_307	WCoast	CCT	2830.56
78	Unspecified	SWPO_308	WCoast	CCT	789.01
92	Unspecified	SWPO_322	Diep	CCT	2113.55
112	Unspecified	SWPO_376	Diep	CCT	1108.8

Table C1b: Duplicate ponds

Object ID	Material	Stormwater pond ID	Catchment	Pond ownership	Estimated area (m²)
116	Unspecified	SWPO_390	Diep	CCT	1684.89
117	Unspecified	SWPO_398	Diep	CCT	928.28
161	Unspecified		Diep	CCT	3329.02
250	Unspecified	SWPO_659	City	CCT	9141.86
259	Unspecified	SWPO_223	Zeekoe	CCT	484.68
260	Unspecified	SWPO_513	Zeekoe	CCT	1994.03
261	Unspecified		Zeekoe	CCT	4929.34
262	Unspecified	SWPO_228	Zeekoe	CCT	5829.89
263	Unspecified	SWPO_659	Zeekoe	CCT	7517.68
269	Unspecified		MPlain	CCT	3351.09
304	Unspecified	SWPO_659	Zeekoe	CCT	27045.77
318	Unspecified	SWPO_550	MPlain	CCT	956.49
392	Unspecified	D21	Eerste	Private	2333.93
530	Unspecified	K10	Diep	CCT	36445.82
556	Unspecified	K27	Eerste	CCT	538.07
756	Unspecified	SWPO_659	Lourens	CCT	584.51
757	Unspecified	SWPO_119	Lourens	CCT	96.97
759	Unspecified	SWPO_121	Lourens	CCT	91.86
760	Unspecified	SWPO_122	Lourens	CCT	652.83
761	Unspecified	SWPO_123	Lourens	CCT	57.3
762	Unspecified	SWPO_124	Lourens	CCT	67.3
766	Unspecified		Lourens	CCT	624.62
795	Unspecified	SWPO_659	Lourens	CCT	50.3
796	Unspecified	SWPO_659	Lourens	CCT	83.13
797	Unspecified		Lourens	CCT	1434.06
830	Unspecified	SWPO_659	Lourens	CCT	1830.51
881	Unspecified	SWPO_243	Zeekoe	CCT	2339.93
885	Unspecified	SWPO_659	Nhoek	CCT	309.03
894	Unspecified	SWPO_206	Nhoek	CCT	2449.5
16523	Unspecified		Zeekoe	CCT	2577.62
27729	Earth		Eerste	CCT	231.31

Table C2a: Merged ponds

Object ID	Material	Stormwater pond ID	Catchment	Pond ownership	Estimated area (m²)
12	Unspecified	SWPO_659	Zeekoe	CCT	32181.73
13	Unspecified	SWPO_659	Zeekoe	CCT	8035.42
470	Unspecified	BL9	Salt	CCT	119.32
471	Unspecified	BL5	Salt	CCT	5272.6
472	Unspecified	BL13	Salt	CCT	979.95
473	Unspecified	BL11	Salt	CCT	640.81
474	Unspecified	BL3	Salt	CCT	2894.56
475	Unspecified	BL8	Salt	CCT	9295.63
476	Unspecified	D5	Eerste	CCT	3443.04
493	Unspecified	B28	Eerste	CCT	11743.7
510	Unspecified	D29	Diep	Private	1790.08
517	Unspecified	D29	Diep	Private	3855.02
521	Unspecified	D5	Eerste	CCT	25286.41
539	Unspecified	B28	Eerste	CCT	56072.34
540	Unspecified	BL9	Salt	CCT	1724.46
543	Unspecified	BL5	Salt	CCT	5705.47
544	Unspecified	BL4	Salt	CCT	15190.48
545	Unspecified	BL3	Salt	CCT	9652.13
546	Unspecified	BL8	Salt	CCT	70073.3
549	Unspecified	BL11	Salt	CCT	14061.29
550	Unspecified	BL13	Salt	CCT	5317.15
563	Unspecified	BL4	Salt	CCT	681.72
658	Grass		Salt	CCT	4101.9
660	Grass		Salt	CCT	4940.22
701	Natural Vegetation		Eerste	Private	4732.7
704	Natural Vegetation		Eerste	Private	321.42
782	Unspecified	SWPO_148	Lourens	CCT	6482.55
783	Unspecified	SWPO_149	Lourens	CCT	10318.83
784	Unspecified	SWPO_150	Lourens	CCT	2598.43
785	Unspecified	SWPO_151	Lourens	CCT	24256.33
786	Unspecified	SWPO_152	Lourens	CCT	4663.27
787	Unspecified	SWPO_153	Lourens	CCT	3538.48
788	Unspecified	SWPO_154	Lourens	CCT	14728.95

Table C2b: Merged ponds

Object ID	Material	Stormwater pond ID	Catchment	Pond ownership	Estimated area (m ²)
789	Unspecified	SWPO_155	Lourens	CCT	1830.54
790	Unspecified	SWPO_156	Lourens	CCT	30885.55
791	Unspecified	SWPO_157	Lourens	CCT	12379.28
792	Unspecified	SWPO_158	Lourens	CCT	2909.46
793	Unspecified	SWPO_159	Lourens	CCT	23955.3
832	Unspecified	SWPO_659	Lourens	CCT	83.13
833	Unspecified	SWPO_659	Lourens	CCT	1434.07

Table C3a: Inner ponds

Object ID	Material	Stormwater pond ID	Catchment	Pond ownership	Estimated area (m ²)	Inner pond type
104	Unspecified	SWPO_335	Diep	CCT	25807.54	Pond
168	Unspecified		Diep	CCT	490.0824	Pond
515	Unspecified	D31	Diep	CCT	1857.04	Pond
518	Unspecified	D27	Diep	CCT	2029.65	Pond
524	Unspecified	D34	Diep	CCT	2705.83	Pond
528	Unspecified	D33	Diep	CCT	1539.41	Pond
532	Unspecified	B1	Diep	CCT	3739.96	Pond
533	Unspecified	B7	Eerste	CCT	3313.12	Pond
534	Unspecified	B8	Eerste	CCT	1069.2	Pond
535	Unspecified	B6	Eerste	CCT	911.87	Pond
536	Unspecified	B12	Eerste	CCT	2044.1	Pond
537	Unspecified	B17	Eerste	CCT	3461.35	Pond
538	Unspecified	B27	Eerste	CCT	10149	Pond
542	Unspecified	BL10	Salt	CCT	4963.27	Pond
553	Unspecified	B4	Eerste	CCT	4353.81	Pond
555	Unspecified	K32	Diep	Private	1218.35	Pond
558	Unspecified	K46	Diep	CCT	4845.06	Pond
559	Unspecified	K47	Diep	CCT	5022.94	Pond
560	Unspecified	B46	Eerste	CCT	675.5	Pond
561	Unspecified	B18	Eerste	CCT	2363.53	Pond
562	Unspecified	D30	Diep	CCT	7060.55	Pond
722	Unspecified		Diep	CCT	487.93	Forebay

Table C3b: Inner ponds

Object ID	Material	Stormwater pond ID	Catchment	Pond ownership	Estimated area (m ²)	Inner pond type
723	Natural Vegetation		Diep	CCT	659.88	Forebay
22528	Earth		Diep	CCT	298.58	Pond
22923	Earth		Diep	CCT	552.78	Pond
22924	Earth		Diep	CCT	741.14	Pond
22928	Unspecified		Diep	Private	895.67	Micro Pond
23325	Concrete		Diep	Private	222.23	Forebay
24124	Earth		Diep	CCT	235.44	Forebay
28129	Earth		Eerste	CCT	335.09	Pond
28529	Earth		Eerste	CCT	380.32	Pond
32939	Earth		Eerste	CCT	2523.02	Pond
32940	Earth		Eerste	CCT	972.02	Pond
43736	Natural Vegetation		Salt	CCT	2164.81	Pond

Table C4: Ponds over informal settlements

Object ID	Stormwater pond ID	Catchment	Pond ownership	Estimated area (m ²)
277	SWPO_659	Zeekoe	CCT	2505.91
295	SWPO_526	Zeekoe	CCT	4140.97
320	SWPO_557	MPlain	CCT	5195.6
336	SWPO_659	MPlain	CCT	19054.17
870	SWPO_650	SLPass	CCT	7394.08
872	SWPO_652	SLPass	CCT	6698.55
891	SWPO_659	Nhoek	CCT	309.03

Table C5a: Anomalies

Object ID	Material	Stormwater pond ID	Catchment	Pond ownership	Estimated area (m²)	Explanation
7	Unspecified	SWPO_659	Sand	CCT	563.85	Over Houses
80	Unspecified	SWPO_310	WCoast	CCT	1346.21	No visible pond and no stormwater (SW) network
81	Unspecified	SWPO_311	WCoast	CCT	1294.8	Over Houses
94	Unspecified	SWPO_659	Diep	CCT	1703.7	Over Houses
111	Unspecified	SWPO_659	Diep	CCT	1808.74	Industrial area
220	Unspecified		Diep	CCT	169.14	Very small and no stormwater (SW) network
251	Unspecified	SWPO_659	City	CCT	9141.86	Over Warehouse in Foreshore
268	Unspecified	SWPO_234	Zeekoe	CCT	200.99	No visible pond and no SW network
274	Unspecified	SWPO_105	MPlain	CCT	2620.61	In a construction site and no SW network
307	Unspecified	SWPO_539	Zeekoe	CCT	14790.09	Over buildings
310	Unspecified	SWPO_542	MPlain	CCT	4310.04	Over buildings
323	Unspecified	SWPO_562	MPlain	CCT	398.74	Small pond and no SW network
325	Unspecified	SWPO_659	MPlain	CCT	524.38	Small pond and no SW network
326	Unspecified	SWPO_565	MPlain	CCT	455.1	Check sat – No SW
327	Unspecified	SWPO_659	MPlain	CCT	313.51	Check sat – No SW
334	Unspecified	SWPO_574	MPlain	CCT	30842.28	Over buildings
366	Unspecified	SWPO_615	MPlain	CCT	5171.39	Over buildings
377	Unspecified	SWPO_627	MPlain	CCT	8049.92	Over built-up area
746	Unspecified	SWPO_106	Eerste	CCT	5067.28	New construction site, ponds have been removed
747	Unspecified	SWPO_107	Eerste	CCT	5055.04	New construction site, ponds have been removed
748	Unspecified	SWPO_108	Eerste	CCT	4945.04	New construction site, ponds have been removed
758	Unspecified	SWPO_120	Lourens	CCT	659.02	Water works
769	Unspecified	SWPO_659	Lourens	CCT	42.96	Small pond and no SW network
771	Unspecified	SWPO_133	Lourens	CCT	36.75	Small pond and no SW network
772	Unspecified	SWPO_659	Lourens	CCT	11813.13	Non-sensical shape and no SW network

Table C5b: Anomalies

Object ID	Material	Stormwater pond ID	Catchment	Pond ownership	Estimated area (m²)	Explanation
774	Unspecified	SWPO_136	Lourens	CCT	1101.31	Small pond and no SW network
781	Unspecified	SWPO_659	Lourens	CCT	968.01	Small pond and no SW network
815	Unspecified	SWPO_181	SLPass	CCT	1910.93	Small pond and no SW network
819	Unspecified		Lourens	CCT	584.37	Water works
820	Unspecified	SWPO_659	Lourens	CCT	96.97	Water works
821	Unspecified	SWPO_659	Lourens	CCT	91.81	Water works
822	Unspecified	SWPO_659	Lourens	CCT	652.65	Water works
823	Unspecified	SWPO_659	Lourens	CCT	57.278	Water works
824	Unspecified	SWPO_659	Lourens	CCT	67.36	Water works
827	Unspecified	SWPO_659	Lourens	CCT	415.44	Small pond and no SW network
829	Unspecified	SWPO_659	Lourens	CCT	261.19	Small pond and no SW network
831	Unspecified	SWPO_659	Lourens	CCT	50.29	Small pond and no SW network
909	Unspecified	SWPO_659	HBay	CCT	124.68	Small pond and no SW network
912	Unspecified	SWPO_659	HBay	CCT	138.99	Small pond and no SW network
913	Unspecified	SWPO_659	HBay	CCT	66.33	Small pond and no SW network
18123	Unspecified		Sand	CCT	251.19	Small pond and no SW network
28928	Unspecified	B47	Eerste	Private	78	Over house in a new estate
43335	Unspecified	K62	Diep	Private	74.31	Small pond and no SW network

Table C6: Reshaped ponds

Object ID	Pond ownership	Original area (m²)	Final area (m²)	Reason for edit
17	CCT	216485.62	165279.30	Removed buildings
55	CCT	11338.56	9218.01	Removed industrial area
59	CCT	1221.25	1744.49	Removed road
76	CCT	1928.08	986.61	Removed houses
140	CCT	2830.509	1645.58	Removed houses
176	CCT	2156.75	3021.57	Didn't match satellite imagery
215	CCT	1663.10	8585.48	Didn't match satellite pond boundary
271	CCT	9572.41	7939.41	Removed buildings
273	CCT	7861.27	9136.26	Removed informal settlement overlap and merged with Pond 336
278	CCT	8114.43	5359.43	Removed buildings
281	CCT	12762.03	9128.05	Remove informal settlement
287	CCT	18645.57	8278.40	Removed buildings
302	CCT	7709.66	1083.94	Removed buildings
313	CCT	9656.08	8904.92	Removed buildings
316	CCT	19268.21	4220.69	Removed buildings
317	CCT	819.11	1598.59	Didn't match satellite imagery
322	CCT	6403.83	5524.32	Removed buildings
351	CCT	50065.94	44166.63	Removed buildings
356	CCT	16738.13	10830.51	Removed buildings
376	CCT	14743.76	8380.18	Removed road
378	CCT	54962.13	44835.69	Removed informal settlement overlap
380	CCT	15814.18	11822.04	Removed informal settlement overlap
513	Private	396.72	887.05	Didn't match satellite imagery
659	CCT	3317.58	4578.29	Didn't match satellite imagery
698	CCT	799.49	4228.23	Didn't match satellite imagery
875	CCT	8527.28	6761.4	Removed buildings
4924	CCT	2247.61	8370.96	Didn't match satellite imagery
9322	CCT	1315.86	1061.78	Removed building
25724	CCT	3194.86	2988.10	Removed informal settlement overlap
40931	CCT	3091.92	4196.47	Removed inner ponds that weren't separate entities
43737	CCT	405.34	27053.86	Didn't match satellite imagery and stormwater network

Appendix D

Table D1a: The sixty-four stormwater ponds visited

Pond ID	Material	Pond class	Catchment	Ownership	Date visited
18	Unspecified	Wet	Salt	CCT	21-Feb-22
118	Unspecified	Dry	Diep	CCT	30-May-21
180	Unspecified	Dry	Diep	CCT	30-May-21
181	Unspecified	Dry	Diep	CCT	30-May-21
182	Unspecified	Dry	Diep	CCT	30-May-21
187	Unspecified	Dry	Diep	CCT	30-May-21
233	Unspecified	Dry	Diep	CCT	30-May-21
256	Unspecified	Dry	Salt	CCT	21-Feb-22
258	Unspecified	Dry	Salt	CCT	21-Feb-22
324	Unspecified	Wet	Eerste	CCT	25-Mar-23
581	Natural Vegetation	Wet	Salt	CCT	21-Feb-22
701	Natural Vegetation	Dry	Eerste	Private	25-Mar-23
702	Natural Vegetation	Dry	Eerste	Private	25-Mar-23
703	Natural Vegetation	Wet	Eerste	Private	25-Mar-23
706	Earth	Dry	Salt	CCT	21-Feb-22
749	Unspecified	Wet	Lourens	CCT	01-Apr-23
750	Unspecified	Dry	Lourens	CCT	01-Apr-23
751	Unspecified	Wet	Lourens	CCT	01-Apr-23
753	Unspecified	Wet	Lourens	CCT	01-Apr-23
754	Unspecified	Wet	Lourens	CCT	01-Apr-23
755	Unspecified	Wet	Lourens	CCT	01-Apr-23
763	Unspecified	Wet	Lourens	CCT	01-Apr-23
764	Unspecified	Dry	Lourens	CCT	01-Apr-23
765	Unspecified	Dry	Lourens	CCT	01-Apr-23
767	Unspecified	Dry	Lourens	CCT	01-Apr-23
768	Unspecified	Dry	Lourens	CCT	01-Apr-23
770	Unspecified	Wet	Lourens	CCT	01-Apr-23
773	Unspecified	Wet	Lourens	CCT	01-Apr-23
775	Unspecified	Dry	Lourens	CCT	01-Apr-23
794	Unspecified	Dry	Lourens	CCT	01-Apr-23
798	Unspecified	Dry	Lourens	CCT	01-Apr-23
799	Unspecified	Dry	Lourens	CCT	01-Apr-23

Table D1b: The sixty-four stormwater ponds visited

Pond ID	Material	Pond class	Catchment	Ownership	Date visited
825	Unspecified	Dry	Lourens	CCT	01-Apr-23
833	Unspecified	Dry	Lourens	CCT	01-Apr-23
835	Unspecified	Dry	Lourens	CCT	01-Apr-23
836	Unspecified	Dry	Lourens	CCT	01-Apr-23
857	Unspecified	Dry	Eerste	CCT	25-Mar-23
858	Unspecified	Dry	Eerste	CCT	25-Mar-23
861	Unspecified	Dry	Lourens	CCT	01-Apr-23
862	Unspecified	Dry	Lourens	CCT	01-Apr-23
863	Unspecified	Dry	Lourens	CCT	01-Apr-23
864	Unspecified	Dry	Lourens	CCT	01-Apr-23
865	Unspecified	Dry	Lourens	CCT	01-Apr-23
866	Unspecified	Dry	Lourens	CCT	01-Apr-23
867	Unspecified	Dry	SLPass	CCT	06-May-23
868	Unspecified	Wet	SLPass	CCT	06-May-23
869	Unspecified	Wet	SLPass	CCT	06-May-23
898	Unspecified	Dry	Sand	CCT	05-Aug-21
899	Unspecified	Dry	Sand	CCT	05-Aug-21
11724	Unspecified	Wet	SLPass	CCT	06-May-23
12123	Unspecified	Dry	SLPass	CCT	06-May-23
13323	Unspecified	Dry	Lourens	CCT	01-Apr-23
13324	Unspecified	Dry	Lourens	CCT	01-Apr-23
13325	Unspecified	Dry	Lourens	CCT	01-Apr-23
13326	Unspecified	Dry	Lourens	CCT	01-Apr-23
13327	Unspecified	Dry	Lourens	CCT	01-Apr-23
13723	Unspecified	Wet	Eerste	CCT	25-Mar-23
13724	Unspecified	Wet	Eerste	CCT	25-Mar-23
13725	Unspecified	Wet	Eerste	CCT	25-Mar-23
13726	Unspecified	Wet	Eerste	CCT	25-Mar-23
16124	Unspecified	Dry	Eerste	CCT	25-Mar-23
17724	Unspecified	Dry	SLPass	CCT	06-May-23
19323	Unspecified	Dry	SLPass	CCT	06-May-23
19324	Unspecified	Dry	SLPass	CCT	06-May-23

Appendix E

The ‘MAR potential’ criterion for the pilot MCA incorporated four indicators of ‘Surficial geology’, ‘Aquifer’, ‘Soil permeability’ and ‘Transmissivity’ (Table 13). It was developed by Evans (2021) for an Honours level BSc (Engineering) dissertation co-supervised by the author.

The ‘Surficial geology’ indicator was constructed using the pond locations and two surficial geology datasets (Bailey & Pitman, 2012; Wright & Jacobs, 2016). The rock type and mean permeability of the surficial geology types were identified through the combined layers (Jasim *et al.*, 2018). The ponds were assigned the surficial geology they intersected using the ‘Join attributes by location’ tool with the ‘intersects’ geometric predicate. Performance scoring was applied to the mean permeability values (Table E1). The Quaternary Sands mean permeability was assigned the most suitable value of one due to the permeable nature of the sand.

Table E1: The surficial geology indicator scores

Surficial geology	Rock type	Typical permeability (m ²)	Mean permeability (m ²)	Performance scale	Pond percentage
Cape Granite	Igneous	10 ⁻²⁰ –10 ⁻¹⁷	10 ^{-18.5}	0.17	4.5%
Malmesbury Shale	Sedimentary	10 ⁻²⁰ –10 ⁻¹⁶	10 ⁻¹¹	0.22	28.2%
Table Mountain Group Sandstone	Sedimentary	10 ⁻¹⁷ –10 ⁻¹⁶	10 ⁻¹⁵	0.56	0.4%
Quaternary Sands	Alluvial	10 ⁻¹³ –10 ⁻⁹	10 ⁻¹¹	1	67.0%

*Assigned the values of unfractured igneous rock.

The ‘Aquifer’ indicator was constructed using the pond locations and the aquifer locations and type (Atkins *et al.*, 2021). Using the ‘Join attributes by location’ tool with the ‘intersects’ geometric predicate, the ponds were assigned the aquifer type and presence. Performance scoring was applied to the aquifer presence and type, with ponds overlying a primary sand aquifer being assigned a score of one and semi-confined aquifers being assigned a score of 0.5, as shown in Table E2. Ponds that do not overlie an aquifer were assigned a score of zero.

Table E2: Aquifer type and presence indicator scores

Aquifer type	Performance scale	Pond percentage
Primary sand aquifer	1	35%
Semi-confined aquifer	0.5	5%
No aquifer	0	60%

The ‘Soil permeability’ indicator was constructed using the pond locations and the International Soil Reference and Information Centre (ISRIC) Soil and Terrain (SOTER) database soil map (World Agroforestry Centre Landscape Portal, 2021). The soil types were described with the aid of the Food and Agriculture Organisation of the United Nations (FAO) classification system. This system used Soil Reference Groups and Qualifiers to assign soil type based on properties and composition. Soil composition and drainage characteristics from the SOTER dataset were then estimated by classifying the soil types into Hydrological Soil Groups (HSGs) and associated hydraulic conductivity ranges (United States Department of Agriculture, 2007). A specific hydraulic conductivity score was then selected for each soil type (Table E3). These selected hydraulic conductivity values were used to normalise the soil types onto the performance scale. ARa was assigned a suitability value of one, as it was the most suitable soil for infiltration. All other scores were assigned proportionally.

Table E3: The soil permeability indicator process and scores

Soil type (FAO Soil Unit Codes)		Hydrological Soil Group	Saturated hydraulic conductivity range **(µm/s)	Selected saturated hydraulic conductivity (µm/s)	Performance scale	Pond percentage (among Quaternary Sands surficial geology)
Ach	Haplic Acrisols	B/C	<10→4.0 or <4.0→0.4	4.0	0.36	1.4%
ARa	Albic Arenosols	A*	>10	11	1	65.7%
LPq	Lithic Leptosols	C	<10→1.0	5.5	0.5	3%
LVh	Haplic Luvisols	B	<10→4.0	6.25	0.57	0%
LXh	Haplic Lixisols	B	<10→4.0	7.6	0.69	1.2%
Ple	Eutric Planosols	B	<10→4.0	6.7	0.61	1.4%
PZh	Haplic Podzols	A/B	>10 or <10→ >4.0	10	0.9	27.3%

*ARa was assigned to HSG A, as its sand percentage was very close to 90% and its clay proportion was within the correct range.

** Saturated Hydraulic Conductivity is provided for the least transmissive layer.

The pond locations and transmissivity categories from the ‘Water Resources of South Africa 2012 Study’ (Bailey & Pitman, 2012) were used for the ‘Transmissivity’ indicator. The ponds were assigned the transmissivity band they intersected with using the ‘Join attributes by location’ tool with the ‘intersects’ geometric predicate. Performance scoring was applied to the rates of flow in the transmissivity categories. The transmissivity categories included the

mediums through which groundwater flow occurs – intergranular flow or through fractures in rock, as well as the rate of flow of water through the medium. For MAR via infiltration ponds, intergranular flow is thought to be the most desirable, as fractured rock flow is more characteristic of confined aquifers. However, only the rate of flow of water was used for value scaling, as the soil permeability indicator already considers infiltration. The highest transmissivity rate (>5.0 l/s) was assigned a value of one, with all other values were scaled according to this, as detailed in Table E4.

Table E4: The transmissivity indicator scores

Transmissivity		Mean of range	Performance scale	Pond percentage
Fractured	0.0–0.1 l/s	0.05	0.01	0.0%
Intergranular and fractured	0.0–0.1 l/s	0.05	0.01	2.6%
Fractured	0.1–0.5 l/s	0.3	0.06	0.1%
Intergranular and fractured	0.1–0.5 l/s	0.3	0.06	1.9%
Intergranular	0.1–0.5 l/s	0.3	0.06	26.2%
Fractured	0.5–2.0 l/s	1.25	0.25	30.5%
Intergranular	0.5–2.0 l/s	1.25	0.25	17.0%
Fractured	2.0–5.0 l/s	3.5	0.7	9.0%
Intergranular	2.0–5.0 l/s	3.5	0.7	12.1%
Intergranular	>5.0 l/s	5	1	0.6%

Table E5 shows a comparison of the indicator scoring.

Table E5: Comparison of MAR potential indicators

Aquifer		Transmissivity		Soil type		Surficial geology	
Scale	Pond percentage	Scale	Pond percentage	Scale	Pond percentage	Scale	Pond percentage
1	36%	1	1%	1	56%	1	67%
0.5	5%	0.7	21%	0.9	22%	0.56	0%
0	59%	0.25	48%	0.69	3%	0.22	28%
		0.06	28%	0.61	1%	0.17	4%
		0.01	3%	0.57	13%		
				0.5	3%		
				0.36	2%		

The ‘MAR potential’ criterion was constructed through the four indicators, with the indicator

scores combined with the weightings in Table E6 using Equation 1 of the weighted additive model.

Table E6: The indicator weightings for the MAR potential criterion for the pilot MCA

Indicator	Weighting
Surficial geology	0.20
Aquifer	0.35
Soil permeability	0.25
Transmissivity	0.20

A point allocation method was adopted for the weighting. It drew on guidance from Russo & Fisher (2015) who advocate for equal weightings or weightings within a small range of variability, usually of 0.1, for MAR suitability studies. Aquifer type and presence was assigned the highest rating, as the presence of an aquifer is essential for MAR. This decision was also supported by Dupont (2018), where hydrogeology was assigned the highest weighting out of the selected criteria, with a value close to 0.30. As aquifer type reflects data included in both the transmissivity and surficial geology, these were not assigned as great a weighting, however it was ensured that these indicators remained within the common variability range of 0.1 by both being assigned weightings of 0.2 (Russo & Fisher, 2015). Sallwey *et al.* (2019) showed that for spreading methods, the presence of hydrological soils was often deemed of critical importance, only second to hydrogeology. Therefore, soil permeability was deemed to be an important criterion, as reflected by its weighting.

Appendix F

4/26/22, 5:28 PM

Gmail - Request for interview - WSC PhD research



Jessica Fell [REDACTED]

Request for interview - WSC PhD research

8 messages

Jessica Fell [REDACTED]

15 March 2022 at 14:36

To [REDACTED]
Cc [REDACTED]

Good day Joanne,

My name is Jessica Fell and I am a PhD student at the University of Cape Town (UCT) evaluating the multi-functional potential of stormwater ponds as planning support for a Water Sensitive transition in Cape Town, please see attached a project overview. My PhD is a sub-component of a UCT project called "Pathways to water resilient South African cities", for which there is a MoU between the City and UCT.

As a key stakeholder, I would like to request to please interview you for an hour as part of the project. If you are willing, please could you let me know your availability as well as completing the attached consent form (which includes a request to record the interview). If you are unable or unwilling to participate, would you have any other colleagues that I could interview? I have attached the relevant research permission from the City as well as the MoU between the City and UCT.

Thank you very much.

I hope to hear from you soon.

Warm regards,

Jessica Fell

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Jessica Fell
PhD Candidate: Civil Engineering
Future Water Institute
University of Cape Town

Figure F1: An example of the email invitation for participation in the interview

Evaluating the multi-functional potential of stormwater ponds: planning support for a WSC transition in Cape Town, South Africa

Jessica Fell | PhD student, University of Cape Town
fell.jessica@gmail.com
Supervisors: Prof Neil Armitage & Dr John Okeidi

A Water Sensitive City with Blue-Green Infrastructure can enhance liveability, resilience and sustainability. Cape Town's existing 850 stormwater ponds offer a potential Water Sensitive City transition pathway, and can be repurposed to provide multi-functional benefits such as managed aquifer recharge, amenity and biodiversity.

When planning for multi-functional stormwater pond development, it is important to determine which benefits are most important and to try maximize different benefits given the spatial context.

This PhD research uses a Multi-Criteria Analysis as a tool for identifying strategic 'priority' stormwater ponds that offer the highest potential to provide multi-functional benefits, corresponding to eight Water Sensitive City planning priorities.

Water Sensitive City planning priority	Proposed criteria
Flood protection significance	Pond capacity check based on Curve Numbers
Activating urban green and blue space	Mean population density in 500m radius of each pond, Estimate of tract population without access to parks
Enhancing biodiversity	Patch cohesion Index, Habitat size, Cape Town Biodiversity Network category presence
Managing water quality	Euclidean distance to informal settlement & WWTW
Increasing water re-use	Aquifer presence and type, Transmissivity, Soil Type, Geology, Depth to water table
Enhancing cultural and heritage associations with water systems	Euclidean distance to culture and heritage resource
Reducing climate change impacts	Average land surface temperature
Education services potential	Euclidean distance to school

Multi-Criteria Analysis
 Criteria selection → Normalisation → Criteria weighting → Evaluation

This PhD research particularly draws on:
 Cape Town's Water Strategy Commitment 5
5 A WATER-SENSITIVE CITY
 "Benchmarking the City of Cape Town as a Water Sensitive City" project
 South African National Land Cover 2020 (Department of Forestry, 2021)
 Formal National Heritage Resources Act Protection layer (City of Cape Town, 2019a)
 Surfacial geology data (Bailey & Pitman, 2012; Wright & Jacobs, 2016), Aquifer boundary and transmissivity data (Bailey & Pitman, 2012), International Soil Reference and Information Centre Soil and Terrain database soil map (World Agroforestry Centre Landscape Portal, 2021).

Example Multi-Criteria Analysis criteria

WSC Priority	Criterion	Attributes (indicator)	Data sources
Activating urban green and blue space	Recreation potential	Mean population density in 500m radius of each pond	2011 census population density (Statistics South Africa, 2011)
Enhancing biodiversity	Biodiversity	Significance of the area for conserving biodiversity and maintaining ecosystem functioning according to the BioNet categories	Terrestrial Biodiversity Network (City of Cape Town, 2019)
Managing water quality	Distance to informal settlement	Euclidean distance to informal settlement	South African National Land Cover 2020 (Department of Forestry, 2021)
Enhancing cultural and heritage associations with water systems	Culture and heritage	Presence in culture and heritage resource sites	Formal National Heritage Resources Act Protection layer (City of Cape Town, 2019a)
Increasing water re-use	Managed Aquifer Recharge potential	Aquifer type and presence, transmissivity, soil permeability, surficial geology and pond surface area	Surfacial geology data (Bailey & Pitman, 2012; Wright & Jacobs, 2016), Aquifer boundary and transmissivity data (Bailey & Pitman, 2012), International Soil Reference and Information Centre Soil and Terrain database soil map (World Agroforestry Centre Landscape Portal, 2021).

Figure F2a: An example of the slideshow sent to participants before the interview

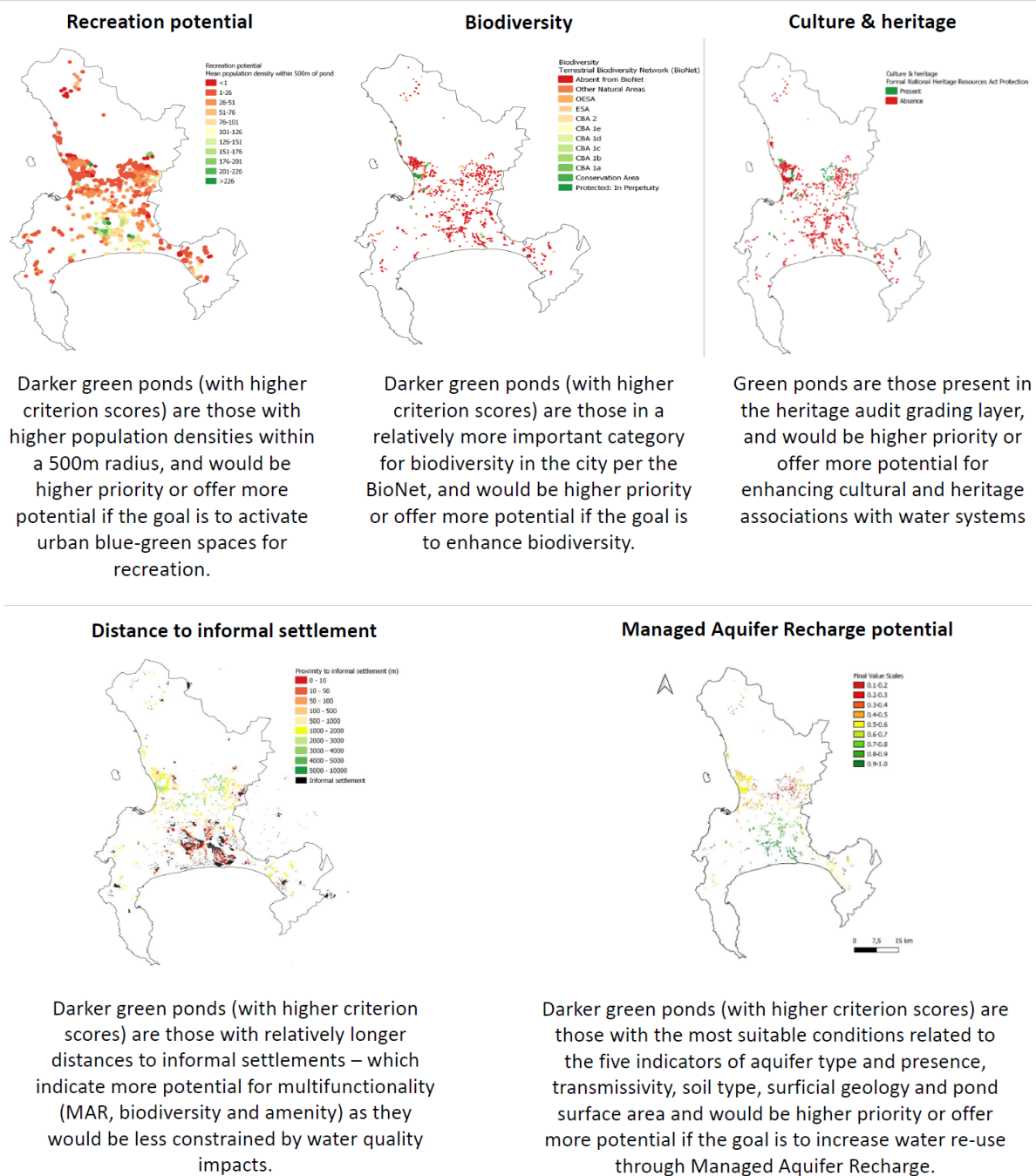


Figure F2b: An example of the slideshow sent to participants before the interview

The slideshow examples in Figure F2 were customised with information on the WSC planning priorities and criteria from the pilot MCA linked to their expertise to ensure there was familiarity with the research.

ETHICS APPLICATION FORM

Please Note:

Any person planning to undertake research in the Faculty of Engineering and the Built Environment (EBE) at the University of Cape Town is required to complete this form before collecting or analysing data. The objective of submitting this application prior to embarking on research is to ensure that the highest ethical standards in research, conducted under the auspices of the EBE Faculty, are met. Please ensure that you have read, and understood the EBE Ethics in Research Handbook (available from the UCT EBE, Research Ethics website) prior to completing this application form: <http://www.ebe.uct.ac.za/ebe/research/ethics1>

APPLICANT'S DETAILS		
Name of principal researcher, student or external applicant		Jessica Fell
Department		Civil Engineering
Preferred email address of applicant:		fell.jessical@gmail.com
If Student	Your Degree: e.g., MSc, PhD, etc.	PhD
	Credit Value of Research: e.g., 60/120/180/360 etc.	360
	Name of Supervisor (if supervised):	Prof Neil Armitage
If this is a research contract, indicate the source of funding/sponsorship		
Project Title		Evaluating multi-functional Blue-Green Infrastructure for a water sensitive Cape Town, South Africa

I hereby undertake to carry out my research in such a way that:

- there is no apparent legal objection to the nature or the method of research; and
- the research will not compromise staff or students or the other responsibilities of the University;
- the stated objective will be achieved, and the findings will have a high degree of validity;
- limitations and alternative interpretations will be considered;
- the findings could be subject to peer review and publicly available; and
- I will comply with the conventions of copyright and avoid any practice that would constitute plagiarism.

APPLICATION BY	Full name	Signature	Date
Principal Researcher/ Student/External applicant	Jessica Fell		30/09/2021
SUPPORTED BY	Full name	Signature	Date
Supervisor (where applicable)	Prof Neil Armitage		1/10/2021
APPROVED BY	Full name	Signature	Date
HOD (or delegated nominee) Final authority for all applicants who have answered NO to all questions in Section 1; and for all Undergraduate research (Including Honours).			
Chair: Faculty EIR Committee For applicants other than undergraduate students who have answered YES to any of the questions in Section 1.	Prof. H. von Blottnitz		03/03/2022

Figure F3: Ethics approval



CONSENT TO PARTICIPATE IN RESEARCH STUDY

Topic of research: Evaluating the multi-functional potential of stormwater ponds: planning support for a WSC transition in Cape Town, South Africa (Jessica Fell, PhD research, Department of Civil Engineering, University of Cape Town)

Cape Town has over 800 retention and detention (stormwater) ponds distributed around the city. The monofunctional ponds were primarily designed to serve a flood control function and can be repurposed to provide multi-functional benefits such as managed aquifer recharge, water quality improvement and enhanced amenity and liveability. In an urbanising city with competition for space and limited budgets, repurposing existing stormwater ponds offers a potential Water Sensitive City (WSC) transition pathway in Cape Town. The stormwater ponds are ~~under-utilised~~, with ad-hoc planning and decision-making processes often resulting in the co-incidental occurrence of multi-benefits and the sub-optimal functioning of the system. The aim of this study is to evaluate the potential of Cape Town's existing 800+ stormwater ponds to provide multi-functional benefits as BGI for a WSC transition in a developing country. This will involve developing relevant evaluation criteria with stakeholder input for a stormwater pond multi-functionality framework and tool and using these to perform a multi-criteria analysis to evaluate and visualize the multi-functional potential of stormwater ponds. You are being asked to participate in this study because you are active in or familiar with the management of stormwater systems and the WSC transition space in Cape Town and South Africa. Please note the following:

- **Participation is voluntary:** Your participation in this project is most valuable but you have the right to withdraw from this project at any stage and are under no obligation to take part in this project.
- **Compensation:** You will not be compensated for participation.
- **Academic research and publications:** Your responses will be solely used for education and research purposes, which may include academic publications.
- **Privacy:** You have a right to refuse to grant permission for your name and position to be included in publications where direct references to information you provided during this interview are used.
- **Interviews:** In the instance where one-on-one interviews are requested, it is your right to decide whether or not the interview may be recorded.

By signing below, you are indicating that you have read and understand the study requirements described above and that you have been given the details of a person to contact should you need to speak about issues which may arise from this interview.

Consent to participate:

- ☐ I agree to participate in the study. ☐ I do not agree to participate

Identity Disclosure: In the event of publications, I give permission to indicate:

- ☐ My name. ☐ My position.

Interview Permission:

- ☐ I agree to be interviewed. ☐ I do not agree to be interviewed.

Interview – Recording Permission:

- ☐ I give permission to be recorded. ☐ I do not give permission to be recorded.

Participant Name: _____

Participant Signature: _____ **Date:** _____

Figure F4: Participant consent form

Non-verbatim interview transcriptions

Interview 1

Principal Professional Officer, Catchment Stormwater and River Management, Bulk Services, Water and Sanitation Directorate, CCT.

General multifunctionality and stormwater ponds

- Multifunctionality as a concept is used a lot and emerged as a strategy to make cities water sensitive, liveable, equitable but it is quite visionary – do you think it has value for Cape Town and is it relevant given the basic service delivery and operational challenges the city faces?
- Multifunctionality is a very relevant concept and something the city needs to pursue in terms of stormwater infrastructure and in some cases, it is already happening, including with some stormwater ponds. However, the concept of multifunctionality needs to be more mainstreamed and an active criterion in the design, it needs to be part of a wider scheme. Some stormwater ponds are multifunctional but unintentionally, they are there to store and attenuate flood water, but as they are GI they inherently provide some secondary benefits sometimes. For instance, wet ponds provide habitat for birds, frogs and other aquatic animals and there is also a cooling effect from them, however they weren't necessarily designed for these benefits.
- What we need to do is start applying the concept from the beginning of the process, so we plan for multifunctionality and ensure that the benefits from multifunctionality are optimised. The stormwater ponds are often multifunctional for the wrong reasons. The dry ponds are dry much of the time, so they are open patches for six to eight months of the year and people invade them and set up housing/informal settlements – the space they are providing for housing is one of the key functionalities of some of the ponds, however come winter they get wet and flooding occurs and disaster ensues. When the stormwater ponds have been invaded there are significant knock-on impacts for water quality, and there are also near impossible social and environmental challenges that come with it that extend far beyond stormwater management.
- Do you think stormwater ponds can be transformed into multifunctional spaces? Can they actually provide benefits beyond flood control?
- I think generally yes but it's got to be focused as to where, how and when. Each location or pond needs to be considered in the context of the catchment, the space, the challenges, the opportunities and so on, so in principle yes, they can be repurposed into multifunctional spaces. However, it won't work everywhere, even if there's potential from a high-level MCA.
- The biggest constraint is the internal institutional issues that are much more complex to

unravel and resolve than any technical or budgetary challenges. You can overcome technical challenges but it's the internal challenges which are deep set in the culture of the organisation and have been entrenched over decades, these challenges are perhaps impossible to overcome. Without finding ways to navigate the internal challenges and people, transforming existing ponds for multifunctionality, or designing new multifunctional ones will not work everywhere and will only work for some where the right people or teams are in place.

- You need to understand the history to understand why multifunctionality and more holistic approaches are difficult to implement in practice; for decades stormwater was part of roads department and its never really left that space, stormwater is seen as a subcomponent of roads. As a result, the perspectives and ways of thinking, related to roads, is that stormwater is waste water, a risk, a hazard and we need to get it off the roads into catchpits and piped off as fast as -possible, and that's the common mindset. That mindset is still with us, its deeply entrenched – that stormwater is waste and let's put it in a pipe Until the current group of road engineers retire and new ones come through, it won't work. The directors of the roads department are civil engineers that did a six-week course in hydrology which said put stormwater in a pipe and that's how it was for decades.
- However, after the drought people wanted to think about it differently, and the stormwater team motivated to leave roads, these talks were from 2017 to the end of 2018, when we had moved over in water department. Since we moved into the Water department there has been significant improvement in managing stormwater and the rivers. However, we had to split the stormwater assets between roads and stormwater, the executive directors made the decision that pipe network road drainage assets and any associated pond used to attenuate flow from that infrastructure would remain under control of the roads department, so the majority of the assets were retained by the Roads department. When the stormwater team moved to the water department and they took ownership of the bulk drainage assets – the main rivers canals, channels and so on. During the split, the people, budgets, contracts, tenders, etc, were split with roads retaining road drainage assets over bulk drainage assets which were given to the stormwater department.
- Most stormwater ponds are still owned and managed under the roads department, only a handful – less than 20% – are the responsibility of the stormwater department. Stormwater largely owns and manages the bigger inland detention ponds and regional ponds in river corridors. No more than 100 ponds are managed by stormwater.
- The ponds under roads' responsibility based on road boundaries under eight roads districts, so for example right of the M5 is D6 and left is D8. The road districts have inappropriate barriers. Each district has a mandate to manage infrastructure and are delegated authority to do manage their district independently, there is some consistency, but each district has a very different management set-up and runs affairs in their own way. Stormwater is a system and should not be a split system based on arbitrary asset ownership decisions, the assets are there to help manage the water, they are just a mechanism. The roads department

only manages the asset and so they have taken their eyes off the water, they don't understand the assets are there to manage the water better.

- Taking a citywide approach or perspective to transforming ponds won't work because of the history and entrenched mindset of stormwater is a nuisance, it may work in some places and there may be some people that recognise it may work – and that won't be because they believe in the principles of SuDS for the benefits it will provide to people, it will be because they believe it won't be a risk. There is too much of a silo perspective to get multifunctional ponds to work. In places where there are good relationships between departments it can work but many people are just extremely difficult to work with on a day-to-day basis. It also depends on getting 'newer' engineers in that have the right skill sets, universities need to train them in WSC and SuDS initiatives. The city is still getting standard engineers that believe stormwater is a nuisance, that have done a six-week hydrology course and that are mentored by the older generation engineers that believe stormwater is a nuisance, so they adopt those same mindsets.
- To get multifunctionality, SuDS and WSC initiatives going the city needs small projects on local scales to prove the benefits that can occur and then start rolling out more similar projects organically, the journey has to be started small. I have a cynical viewpoint, the city doesn't practice what it preaches, the city makes developers put in SuDS but they don't do it themselves, there are many examples of the city not putting in SuDS to current large developments of theirs. For example, the large MyCiti bus route roll-out that had a huge budget, the gardens were on raised beds with conventional stormwater pipes that sent the water away rather than using it to irrigate the gardens. It would have been very easy to put in SuDS but they don't do it with their own projects.
- In terms of the stormwater assets that are best suited for multifunctionality, the waterways (rivers or canals) are the main asset type where it would work. Most canals are monofunctional and sterile and they can be transformed to enhance biodiversity, you can put in treatment trains, pathway which runs along edge, educational signage, you can knock down part of the canal wall to enhance it. There are some examples, for instance the Ross common. Ponds do also offer a unique opportunity for multifunctionality as there are so many of them and they are so dispersed across city, you could hone in on the top 10 or 20 and go from there.

WSC planning priorities and criteria

- I have created seven WSC planning priorities based on literature, policy documents and the benchmarking study. I am going to go through each priority, the proposed criteria or dataset and ask for your inputs, comments on the datasets and so on.
- Regarding the relevancy of the WSC planning priorities, if you take away institutional issues, the planning priorities spot on. They closely match the prioritisation criteria for

liveable urban waterways of which there are six criteria.

- Perhaps reword the Increasing water re-use to be more specifically on groundwater or aquifer recharge. Obviously, a pond that ticks all these planning priority boxes is higher priority. Perhaps you can bring in some second order metrics – such as cost or affordability which brings in capex and opex costs, so prioritising ponds where there is the lowest whole life cost including repairs and maintenance. There is always a preference over passive management versus active management. The safety of accessing a pond for amenity or to do work or maintenance is worth considering, so avoiding crime hotspots as theft and vandalism are constraints, or ensuring what you put in is vandal or theft proof, you want to choose ponds in places where there is a lower risk for theft and vandalism. You could include cost and safety as a second order criteria to consider once you have a shortlist.
- Amenity potential will be determined by each pond and by where they are there are opportunities, wet ponds could be parks in summer and wet ponds in winter.
- For biodiversity potential it will depend on the pond type, the seasonality will impact the biodiversity (and amenity) functionality. The ponds that are wet or get wetter in winter will have more biodiversity compared to the dry ponds. There are trade-offs though, a soccer pitch has amenity value but it is a dustbowl with low biodiversity. Biodiversity will be particularly enhanced with wet ponds as they support much more biodiversity comparatively speaking.

Increasing access to blue-green space

- Next is activating urban blue-green spaces, so using ponds for amenity purposes. In my example I have looked at recreation potential to indicate a higher level of potential use of the pond as recreation space by people as they live in close proximity to it.
- In terms of what to measure, which of the following would you prioritise: ponds in areas where people lack access to green space or ponds where people live in close proximity to the space so could use it? Or would you prioritise both?
- Areas where there is lack of access could be a very good criteria for repurposing the ponds, however for amenity it is hard to choose between land to live in and land for recreation. Given Maslow's hierarchy of needs, if people don't have housing they don't want amenity so a lot is tied into availability of housing. An example in an area where housing is lacking and there are land invasions, Khayelitsha wetland park is wonderful green asset with a gym and gardens but it's been invaded for housing. With some ponds, in a week the land will be used for housing. Some of my colleagues think these kinds of spaces should be fenced in.
- In terms of access to ponds for amenity – is walking distance more importance or public transport routes for accessing a pond?

- Walking distance more important than public transport, people will take public transport to nicer places such as green point urban park or the beach.

Managing water quality

- The next priority is managing water quality, so how can water quality concerns that would limit other functions like amenity and MAR be considered? In my example I've looked at the land cover type in the form of distance to informal settlements, so 36% of the ponds are within 500 m of an informal settlement.
- Are there any other land cover types or known pollutant sources like a WWTW or industrial land cover that should be incorporated? Should proximity to these be considered a limiting factor, so the pond is less prioritised?
- Water quality is an important constraint where you want people to come and use it, so it matters depending on the function. A green space with polluted water is still providing UHI reduction, but if it's a space for recreation the water quality needs to be up to the recreation water quality standards. Water quality is a big constraint for a lot of things. A well designed multifunctional pond should have a cleaning function, a wet pond can purify some of the water through natural processes. WWTWs discharge into main rivers which are unlikely to have ponds on the rivers, so it is probably not worth looking at these.
- For water quality, things to consider are ponds in catchments upstream from heavily urbanised spaces, CBDs, main roads, industrial spaces – heavy and light such as Maitland and Ndabeni, ponds that drain those catchments. Ponds that drain N1 and N2, ponds that drain the airport, any main transport routes, any land covers that could result in higher contaminants. Perhaps look at sewer overflow datasets, they might not give you raw data, but they have heat maps to show red circles where sewer overflows are, it will pinpoint the main red circles of sewer hotspot overflows and you can see where there are ponds in that area.

Increasing water re-use

- For MAR potential I have considered four indicators of aquifer type and presence, transmissivity, soil type, surficial geology and pond surface area? Any other sub criteria or comments?
- A lot of ponds have under drains that collect seepage water and take it away, these would have to be transformed. Any lined ponds can't recharge the aquifer – clay lined or plastic liner.

Enhancing cultural and heritage associations with water systems

- Enhancing cultural and heritage associations with water systems, I looked for presence of the ponds in the heritage resources sites from the heritage auditing layer. Any
- comments? Any other datasets that I could use to see where ponds are near heritage sites?
- Culture needs to be a criterion.

Reducing climate change impacts

- Climate change – only one element of climate change is heat, a lot of your other criteria talk to climate change such as flood protection, it impacts most of the planning priorities. Perhaps rephrase it as reducing UHI.

Education services potential

- Education services potential has to at least be a 3, but depends on the school and space, just because you are 100 m from a pond doesn't mean it will be used. Perhaps look at a subset of schools that are part of eco school program, those schools talk to educating through nature.
- Another potential criterion is economic opportunities, job creation and livelihood enhancement – it will have to be second order and will depend on what is done with the pond. The criterion could be opportunities to create green jobs/circular economy jobs. Some ponds depending on what is done with them will require active management and new jobs could be created through existing initiatives or a new recycling initiative, there may be other ways to unlock other benefits and particular job opportunities.
- Should equity be brought in by immediately prioritising ponds near informal settlements or lower income areas?
- Is there anyone you think I should speak to? For the Urban Catalytic projects in Mitchells plain area, they may even be looking at a stormwater pond specifically.

Interview 2

Principal Professional Officer, Urban Sustainability Unit, Urban Planning and Design
Department, Spatial Planning and Environment Directorate, CCT.

General multifunctionality and stormwater ponds

- Multifunctionality as a concept is used a lot and emerged as a strategy to make cities water sensitive, liveable, equitable but it is quite visionary – do you think it has value for Cape Town and is it relevant given the basic service delivery and operational challenges the city faces?

- The operational aspects are the hardest. With wet and dry ponds the maintenance is the problem, especially because they are often built on the edge of informal settlements so the issue becomes who is going to look after it? Even though plans and strategies set these things out nicely they are hard in practice. The river system (Diep River) by Dunoon is one of the biggest and is giving the city biggest problem, particularly between the informal settlement and the river. The Diep river is in such chaos, the ratepayers are angry at city, and the problems lie with the practicalities of things. In the city plans you have to provide for these areas if considering multifunctionality or GI, but who does it sit with for ownership and maintenance, where does it fall – on the engineering side, or the ecological protection side, or environmental planners – these different departments end up bumping into each other. The planner comes in after it has been designed and planned for and says what happened here with the operational aspects. It's all fine on paper in plans that there is open space, in the urban design context of how it looks, we can design our way out of any problem, but who is looking after it. My colleague designed the Hannover Park which has a dry pond that can be used as a skate park in the dry season but housing has become a bigger problem or priority than green space.
- In dry periods, especially during the drought years, ponds and green spaces are attractive as housing areas. Also, informal settlement housing is sometimes strategically located on areas that will flood, because when it floods and homes and possessions are lost, the city has to provide housing for the displaced. Also, in the informal settlements you have foreigners who are only there for a few months so they don't care about keeping the space maintained. Often personal basic needs are more important than community needs – basic needs trump everything.
- If you have capital then you can design or engineer your way out of anything, but once you've designed then what then.
- If there is a gap or open space, then people will use it for dumping. I've worked in the UK and Europe, and even there if you don't give an open space a use or make it valuable then it doesn't have value.
- I am looking at stormwater ponds specifically for multifunctionality; do you think stormwater ponds can be repurposed into multifunctional spaces? Can they actually provide benefits beyond flood control?
- Do you think it is worthwhile upgrading stormwater ponds for multifunctionality to fulfil the CCT's WSC commitment? Are there better ways or infrastructure types with which to do this with?
- Yes, it is always worth considering them for upgrading into multifunctional spaces. The siloed nature of government is always brought up as a barrier, but it is not always negative, you have to give a specialist job to a guy who knows what they are doing. There is a chain to how multifunctional spaces are designed, once each specialist finishes, they are done and it moves onto the next, it's not thought about in an integrated way altogether.

- If you could figure out the chain for designing, implementing and managing multifunctional stormwater ponds – who is the beginning, who hands over to whom when, that would be useful, along with considering the life span of a pond. I'm a visionary and always thinking 100 years ahead and then I have to sell the idea and find the asset owner and that's a certain line department with a certain remit. A stormwater pond's purpose is to hold stormwater back, so it fits with stormwater department but now you want it to be a recreational facility and now the risks are so high. Now its open and there's risk, people can drown in it. Safety and security trumps everything, and its complicated as the line is blurred over who looks after it.
- So yes we would like to turn ponds into multifunctional spaces but the caveat is it then sits in different boxes whose budgets do not align together. Each department has different critical priority lists.
- Century City is a great example of multifunctional blue green spaces.

WSC planning priorities and criteria

- I have created seven WSC planning priorities based on literature, policy documents and the benchmarking study. I am going to go through each priority, the proposed criteria or dataset and ask for your inputs, comments on the datasets and so on.

Increasing access to blue-green space

- Next is activating urban blue-green spaces, so using ponds for amenity purposes. In my example I have looked at recreation potential to indicate a higher level of potential use of the pond as recreation space by people as they live in close proximity to it.
- In terms of what to measure, which of the following would you prioritise: ponds in areas where people lack access to green space or ponds where people live in close proximity to the space so could use it? Or would you prioritise both?
- The size of the pond will impact what you can use it for. The pond radius will be about the size of it, for x ppl you need x open space. The use and type of recreation also impacts the sizing needs, if you just want to sit under tree or to play a sports game. The size will dictate the use more than the other way around. The environmental department may have a number for the open space required for certain densities.
- Basic services trump recreation, health and safety trumps recreation.
- Size determines use and size determines who uses it and how often – there are gender aspects. Women need smaller spaces and men need larger spaces. Bigger spaces are often used for football while girls don't kick ball, girls want trees and smaller spaces to gather and meet.

- The type of access people require will be based on the context – the context is the determinant, where are they and what are they situated near. For example, if the pond is not connected to the BioNet you could provide more access. The environment should come first, even if it means giving a space a use which means that no one comes close to it.
- Do this high-level assessment in a general manner but try to bring it to the ground a bit.
- In terms of access to ponds for amenity – is walking distance more importance or public transport routes for accessing a pond?

Enhancing biodiversity

- For biodiversity, is habitat size or using ponds to enhance landscape connectivity more important?
- When considering biodiversity, you may need to distinguish between wet and dry ponds. The connect or stepping stone effect is important. In District Six, the project is eating up land for the housing, and there is a ratio for x amount of houses I need x amount of retention ponds. It's important but hard to do in practice. All aspects are important but from different angles different things will be important.
- Try and access the biodiversity dataset of the city's wetlands, it could help your study.

Managing water quality

- The next priority is managing water quality, so how can water quality concerns that would limit other functions like amenity and MAR be considered? In my example I've looked at the land cover type in the form of distance to informal settlements, so 36% of the ponds are within 500 m of an informal settlement.
- Are there any other land cover types or known pollutant sources like a WWTW or industrial land cover or main transport route that should be incorporated?
- It will depend on all land covers. However, to blame a land cover is an easy way out, so not engineering or farming or informal settlements because they are badly managed and their discharge is not good. It's not always the land cover but the way its managed and the services provided.

Increasing water re-use

- For MAR potential I have considered four indicators of aquifer type and presence, transmissivity, soil type and surficial geology. Any other sub criteria or comments?
- When I look at the MAR potential maps, they are telling me different stories, there is an

aquifer story and then a mountain story. In flat areas, there is more water and the question is how to hold the water. The topography plays a big role, we go higher and lower than sea level – there’s an impact on where they are located and then the use.

- When looking at the map, I’m wondering why is one always coming out as the baddie or best one, that’s something to step back and look at. If you had best, medium or bad, perhaps you could highlight the top three bad, medium and worst. Do some always give best or worse and what are their characteristics. Why are the good ones working and so on? This is how to investigate levers or enablers.
- Bring in multiple layers or aspects such as the mountain, informal settlements and aquifers and population density. Overlay the ponds with spatial datasets.
- Consider speaking to the metro planners and look at the Municipal Spatial Development Framework.
- Always start with nature first.
- Consider using Dunoon and the Diep River as a case study.
- Change the managing water quality name as it doesn’t make sense.

Enhancing cultural and heritage associations with water systems

- Enhancing cultural and heritage associations with water systems, I looked for presence of the ponds in the heritage resources sites from the heritage auditing layer. Any comments? Any other datasets that I could use to see where ponds are near heritage sites?

Interview 3

Principal Professional Officer: Decision Support Systems & Data Management, Bulk Water Branch, Water and Sanitation Directorate, CCT.

General multifunctionality and stormwater ponds

- Multifunctionality as a concept is used a lot and emerged as a strategy to make cities water sensitive, liveable, equitable but it is quite visionary – do you think it has value for Cape Town and is it relevant given the basic service delivery and operational challenges the city faces?
- Multifunctionality is important and it’s got relevance but I’m not sure how it’s interpreted for and what level of functionalities you would target. It may be targeting different levels of functionality. For example, in some suburbs you could use ponds for tennis courts while other areas you would have to go for green space. As its infrastructure that is used around 10 or 20 days a year, then why not use for multifunctionality.

- I am looking at stormwater ponds specifically for multifunctionality; do you think stormwater ponds can be repurposed into multifunctional spaces? Can they actually provide benefits beyond flood control?
- Yes, the stormwater ponds can be repurposed into multifunctional spaces but the complex issue at the moment but who does it, not whether it can or can't be done. Repurposing the ponds isn't particularly difficult, but who does it is difficult. Doing projects such as this is a contested space with some seniors taking roles they shouldn't, people who don't understand what the ponds are fundamentally for. It is very easy to repurpose ponds or rivers or green spaces but does it still deliver on flood control fundamentals? In the SuDS guidelines there is the hierarchy triangle, which says that quantity is the top priority. Some people only focus on amenity and biodiversity and and forget about the engineering or flood protection side.
- Actually repurposing the ponds and having the good intentions is easy but the practical implementation is tough – who does it rather than whether it can be done is the primary concern.
- First and foremost, these ponds provide flood control. For the Liesbeek River, Elsieskraal River, they have been transformed with emphasis on amenity and biodiversity and this work has resulted in a situation that will result in flooding in the next 10 years. Once you've transformed it, it's hard to walk back once you've compromised on flood control and quantity capacity, it wasn't addressed or considered holistically from the beginning. Once flood control capacity has been changed through transformation, who takes ownership and management responsibilities? For example, the pump stations leave a lot to be desired in terms of the telemetry and systems management. If these kinds of older systems are transformed, who takes over the Internet of Things, operations, management and capacity?
- Do you think it is worthwhile upgrading stormwater ponds for multifunctionality to fulfil the CCT's WSC commitment? Are there better ways or infrastructure types with which to do this with?
- From a research perspective, ponds are most appropriate and it's a point in space to concentrate on, you can analyse them and form an argument, check the quality and so on, it can be used for a controlled study. In terms of wider Cape Town it is fine to focus on. The rivers are also potential sites to work on, as are bioretention systems as people find them attractive. Rivers are harder to focus on because the lines are blurred.
- Does the size of a stormwater pond influence its potential for multifunctionality?
- Wet and dry pond distinctions impact the potential for multifunctionality. Satellite data can help with mapping out some of the ponds, recent remote sensing data can assist in distinguishing between wet and dry ponds.
- For distinguishing between wet and dry ponds, remote sensing data can help, you can use

vegetation to give an indication of wet and dry areas and then differentiate. You could train it on a couple ponds then you can automate it. How much water is in the vegetation and using that as a proxy. You can use South African National Space Agency data also, it shows seasonality on water bodies.

WSC planning priorities and criteria

- I have created seven WSC planning priorities based on literature, policy documents and the benchmarking study. I am going to go through each priority, the proposed criteria or dataset and ask for your inputs, comments on the datasets and so on.

Increasing access to blue-green space

- Next is activating urban blue-green spaces, so using ponds for amenity purposes. In my example I have looked at recreation potential to indicate a higher level of potential use of the pond as recreation space by people as they live in close proximity to it.
- In terms of what to measure, which of the following would you prioritise: ponds in areas where people lack access to green space or ponds where people live in close proximity to the space so could use it? Or would you prioritise both?
- Perhaps mask out the Atlantis wellfield ponds, you won't be allowed to touch them.
- In terms of access to ponds for amenity – is walking distance more importance or public transport routes for accessing a pond? Walking distance is more important, if people are going to the effort of getting transport, they will go to an area that is already developed and is nicer, there are enough good public parks to go to.
- Regarding security concerns, from a practical perspective should ponds near crime hotspots not be prioritised for amenity as there is more risk and thus people are less likely to use them for amenity? Any other comments?
- You can use security as a second level criteria. Security issues might result in a decrease of support for an initiative. If you bring in security issues too soon you may dilute the potential of the ponds for multifunctionality.
- How do wet versus dry ponds impact recreation potential?
- Pond types in terms of wet versus dry should maybe be a factor. A factor here is vegetated areas or wetlands being a crime risk. Dry ponds may be less risky as they are grassed without tall bushes and trees. A step is to ask if certain ponds are a priority, how do we adjust them and determine what is the amenity we will offer.
- Does pond size have an impact on recreation potential?

- Yes, but for pond size you won't find a small city owned pond, they are not designed that way.

Enhancing biodiversity

- For biodiversity, is habitat size or using ponds to enhance landscape connectivity more important?
- Look at the aquatic city datasets.
- Landscape connectivity is more important than habitat size. The city already has large enough green areas and reserves such as Table Mountain and various vleis. Connectivity is of more benefit to the city.
- How do wet versus dry ponds impact on biodiversity?
- Wet ponds offers more biodiversity potential than dry ponds but then you run into security issues, so it ultimately comes down to the appropriateness of choice for the particular area.

Managing water quality

- The next priority is managing water quality, so how can water quality concerns that would limit other functions like amenity and MAR be considered? In my example I've looked at the land cover type in the form of distance to informal settlements, so 36% of the ponds are within 500 m of an informal settlement: Darker green ponds (with higher criterion scores) are those with relatively longer distances to informal settlements – which indicate more potential for multifunctionality (MAR, biodiversity and amenity) as they would be less constrained by water quality impacts. Are there any other land cover types or known pollutant sources like a WWTW or industrial land cover or main transport route that should be incorporated?
- Pump stations and WWTWs are an issue, the city has those datasets – those points could be supplied.
- For sewer overflow hotspots you can use C3 notifications from the city's system, but those C3 notifications are misleading as people in high income brackets make more complaints more frequently.

Increasing water re-use

- For MAR potential I have considered four indicators of aquifer type and presence, transmissivity, soil type and surficial geology? Any other sub criteria or comments?
- The depth to aquifer criterion is important as it relates to filtration of the water. The water

needs a small amount of filtration before to improve water quality. I think there is an official figure of needing a 1 m to 2 m gap between the aquifer and the surface for filtration. Some ponds on the Cape Flats Aquifer for example are basically in the aquifer as it is at the ground surface so any pollution goes straight in.

- If the depth to water table is less than 1 m to 2 m there is a water quality problem.

Enhancing cultural and heritage associations with water systems

- Enhancing cultural and heritage associations with water systems, I looked for presence of the ponds in the heritage resources sites from the heritage auditing layer. Any comments? Any other datasets that I could use to see where ponds are near heritage sites?
- There are culture and heritage datasets in the city.
- From an academic perspective, yes, its relevant to bring the culture and heritage elements in. Especially in relation to what is happening at River Club with trying to integrate indigenous elements.

Reducing climate change impacts

- For this criterion, I am considering where is the UHI effect more pronounced based on higher land surface temperatures, and prioritising those ponds as BGI provides a cooling effect.
- If you are going to use land surface temperatures, you need to think about global dataset cell sizes for the UHI.
- If you can't get temperature datasets, you can use vegetation as a proxy as it will give the same answer as land surface temperatures. The data for land surface temperatures may be too low resolution with large cell sizes.
- You can use canopy cover for the city which highlights the areas where you don't have green/vegetation. You can use the RGB and infrared, looking at the difference between red and infrared, if there is no vegetation it will pick up nothing.
- Email my contact I'll give you for vegetation datasets.

Education services potential

- I am considering proximity to schools.
- You can request a dataset on the location of schools.
- This criterion is worthwhile as a first order consideration. There are also other benefits besides education opportunities, there are benefits in terms of ownership, schools taking

ownership of pond.

General

- Ponds near informal settlements and intersecting housing concerns are a challenge.
- There are risks of a dry pond becoming invaded, but these are perhaps secondary concerns on the ownership side.
- Is there anyone you think I should speak to? Perhaps the head of the WSC committee at CCT.
- It's not worth speaking to anyone in roads as they are not focused on this kind of strategic work.

Interview 4

Senior Geospatial Analyst, Groundwater consultancy, Cape Town.

General multifunctionality and stormwater ponds

- Multifunctionality as a concept is used a lot and emerged as a strategy to make cities water sensitive, liveable, equitable but it is quite visionary – do you think it has value for Cape Town and is it relevant given the basic service delivery and operational challenges the city faces?
- It is definitely relevant and the city needs it to be relevant, they are under pressure to have as many co-benefits as possible. I went to a workshop I 2019 where they showed a pond in the rainy season which turned into a soccer field, a multiuse space. It's a way forward to meet developmental standards in terms of ecology and social aspects.
- I am looking at stormwater ponds specifically for multifunctionality; do you think stormwater ponds can be repurposed into multifunctional spaces? Can they actually provide benefits beyond flood control?
- Look at the work being done with green corridors to feed into the CCT Spatial Development Framework. Link existing canals and integrate stormwater ponds more into that system.
- I'm not sure all the ponds in the dataset are retention and detention, some are misassigned as wetland or surface depression, take into account some aren't ponds but are wetlands.
- When trying to turn the ponds into recreation space, some are not in a good state and I'm not sure if you actually want them to be used for recreation. There could be an adopt a stormwater pond program for residents to target more critical ones, linked to open canals

or pre-existing community efforts.

- Do you think it is worthwhile upgrading stormwater ponds for multifunctionality to fulfil the CCT's WSC commitment? Are there better ways or infrastructure types with which to do this with?

WSC planning priorities and criteria

- I have created seven WSC planning priorities based on literature, policy documents and the benchmarking study. I am going to go through each priority, the proposed criteria or dataset and ask for your inputs, comments on the datasets and so on.

Increasing access to blue-green space

- Next is activating urban blue-green spaces, so using ponds for amenity purposes. In my example I have looked at recreation potential to indicate a higher level of potential use of the pond as recreation space by people as they live in close proximity to it.
- In terms of what to measure, which of the following would you prioritise: ponds in areas where people lack access to green space or ponds where people live in close proximity to the space so could use it? Or would you prioritise both?
- In terms of access to ponds for amenity – is walking distance more importance or public transport routes for accessing a pond?
- Regarding security concerns, from a practical perspective should ponds near crime hotspots not be prioritised for amenity as there is more risk and thus people are less likely to use them for amenity? Any other comments?
- How do wet versus dry ponds impact recreation potential?
- Does pond size have an impact on recreation potential?
- Consider existing amenities, is there another sports field nearby and so on then the likelihood of that pond being a draw card is low. In Tableview or central Cape Flats, there might be existing sports fields or amenities.
- Look at the parks and recreation layer on the CCT Open Data Portal, its broken down into different categories. If there is a pre-existing soccer field nearby, you may not want to prioritise the pond. It could be spun the other way that a pond near a football pitch should be prioritised as it's a health risk to be close to a polluted pond. You could look at are there any other sports field within a 1 km, as a second buffer.

Enhancing biodiversity

- For biodiversity, is habitat size or using ponds to enhance landscape connectivity more important?
- Consider both habitat size and connectivity. From a CCT Spatial Development perspective linking the systems and making them corridors is more viable than considering habitat size, but you may be able to link them through open canals or culverts.

Managing water quality

- The next priority is managing water quality, so how can water quality concerns that would limit other functions like amenity and MAR be considered? In my example I've looked at the land cover type in the form of distance to informal settlements, so 36% of the ponds are within 500 m of an informal settlement: Darker green ponds (with higher criterion scores) are those with relatively longer distances to informal settlements – which indicate more potential for multifunctionality (MAR, biodiversity and amenity) as they would be less constrained by water quality impacts. Are there any other land cover types or known pollutant sources like a WWTW or industrial land cover or main transport route that should be incorporated?
- Look at rewording it to be potential contaminating activities (PCA). Look at the 2020 land cover map. Informal settlements are a challenge. Also look at sewer network layer. Septic tanks are a no go. Consider light industrial land covers and open canals. A researcher at the Cape Peninsula University of Technology tried to identify illegal discharges into the canal network, where light industry is releasing straight into the canal.
- Consider once off high impact events versus continuous low impact land covers such as informal settlements. An industry discharge may be once off high magnitude while informal settlement discharges are lower impact with a continuous signal.
- There is a decommissioned landfill sites database.

Enhancing cultural and heritage associations with water systems

- Enhancing cultural and heritage associations with water systems, I looked for presence of the ponds in the heritage resources sites from the heritage auditing layer. Any comments? Any other datasets that I could use to see where ponds are near heritage sites?
- I'm not sure of other datasets, and there will be informal heritage sites to include. This is a point or limitation to make of the heritage layer.
- It might have to be second order as there may not be enough data.

Reducing climate change impacts

- Where is the UHI effect more pronounced based on higher land surface temperatures, and prioritising those ponds as BGI provides a cooling effect.
- For data access, sentinel satellite does have a 10 m grid, with near infrared and a thermal band. Landsat 8 and 9 do have thermal bands and do thermal band ratios, these products may be downloadable. Historical data will only have a 30 m grid for Landsat though.
- You could do a mini validation step to prove that green areas do provide more cooling. You could look at what the land surface temperatures were before an informal settlement expanded and after, was it cooler before the informal settlement was there? Check with historical data and use two or three points across the city and tie the land surface temperatures down. The Climate System Analysis Group at UCT has wind direction data, you could look at an area being windy so the UHI shouldn't be as pronounced.
- If the land surface temperatures data doesn't work you can fall back onto the vegetation data as proxy.

Education services potential

- You could also look at proximity to community centres, the religious communities are also active in the green areas. You could use schools as a 50% weighting, community centres as 25% and Non-Governmental Organisation and religious institutions as 25%. There is a lot of adult education happening on top of school children.
- For the activating urban blue green spaces priority you could do a faster analysis of how close is the pond to an existing waterway using a pond and river buffered by 500 m and see where they intersect. You could collapse the two to get a quick order of magnitude answer.

Increasing water re-use

- The official accommodation space is 1 m. When the water table is at the surface recharge can't happen. The deeper the water is higher the hydraulic gradient is so the faster the recharge could happen.
- Surficial geology and soil permeability cancel out in urban area. Rather ask is it quaternary alluvium and then do a binary assessment. The mountains are where the confined aquifers are. Rather use surface geology as a mask layer.
- The Table Mountain Group and Southern Planning District aquifers are hard rock (aquifer type 1). However, they are two aquifers sitting on top of each other and the one is confined while the other is semi-confined. There is a shallow and then a deeper section, it's accessing two different hydrological systems.

- The Atlantis and Cape Flats Aquifer aren't confined but it doesn't mean someone in the city bowl can't access sub surface water just because there is no aquifer there. Are you focusing on retention ponds on primary aquifers or considering anything that can interact with groundwater.
- It is more nuanced than there is a confined and semi-confined aquifer. Are you focusing on Cape Town aquifers identified for bulk water production and resilience building or the potential to use groundwater across the city from an individual scale? If it's the latter, then you need a second layer showing shallow subsection surfaces of water. Phrase it that you are focusing on unconfined aquifer recharge not subsurface/groundwater recharge in general.
- Some areas are accessing groundwater from a 20 or 30 m packet of sand acting as a sponge.
- You can have a sand packet that is a sand dam aquifer, which would be called groundwater not an aquifer as it doesn't meet certain criteria to be called a primary aquifer. There are primary and secondary aquifers and so on.
- You could pump the Cape Flats Aquifer for 2 years without recharging it.
- For the sake of your study clarify what do you mean by aquifer and what lens you are using to consider or include groundwater. Is it from a bulk water and water resilience focus? The next phase after this would be to include localised groundwater.
- State upfront the study is considering primary aquifers at a large scale used at a bulk water city supply level.
- If there is no aquifer some recharge still occurs but is localised; surface water filling localised aquifers.
- Understand well point use, draw down water before it gets to primary aquifer.
- Transmissivity doesn't indicate direction of flow. The direction of sub surface flow in a given unit is an important consideration, as you may pump water here then water leaks out further away.
- You do not need to include a pond surface areas indicator; I don't think it's worth it.
- For surface geology have a yes or no and if it's a no then give it a zero/Boolean and mask it out.
- Water levels fluctuate so the criterion should have a lower weighting overall. Seasonality and water levels can vary quite drastically so disclose that the data may not be completely reflective of a complex reality. You may need to look at the highest and lowest year for the Cape Flats Aquifer and Atlantis seasonality.
- There is some tightening down of the focus and being more specific, there are misconceptions around aquifers and groundwater. This project considers primary aquifers of a sufficient scale, the other areas are important as they are sinks of surface water.

- Distinguish as primary sand aquifers and hard rock aquifers. Rock aquifers are peripheral to existing basins. If its hard rock its zero, primary aquifers rank higher.
- Define what no aquifer is, as in its not sitting on a primary aquifer but it still can contribute to groundwater recharge.
- Give the ponds over semi-confined aquifers a score of zero, its only 5% of ponds and they are sitting in mountain areas – Kommetjie and Noordhoek way.
- Give the other ponds over ‘no aquifer’ a score of 0.1 as recharge can happen, call it localised groundwater. It’s still going into the ground and feeding groundwater but not the primary aquifer.
- Give the ponds over a primary sand aquifer a score of one as it is the most ideal for your research.
- Define soil water versus aquifer.
- Upfront say the research is focusing on a bulk water level which is sand aquifers and potentially high yielding rock aquifers. Local aquifers are not high yielding enough to be considered sources of water on a larger scale.

Interview 5

Principal Professional Officer, Resilience Department, Future Planning and Resilience, CCT.

General multifunctionality and stormwater ponds

- Multifunctionality as a concept is used a lot and emerged as a strategy to make cities water sensitive, liveable, equitable but it is quite visionary – do you think it has value for CT and is it relevant for CT given the basic service delivery and operational challenges the city faces?
- Multifunctionality is absolutely important, you can make the argument that one piece of infrastructure can do different things. You can make a better business case for multifunctionality, if something only does one thing it doesn’t necessarily make financial sense. Unfortunately, we don’t set our arguments up in such a way to unpack multifunctionality.
- If we separate functions out to the individual parts, say only to a stormwater management function, then how is the city going to start building climate adaptability? There is no doubt that from an installation, maintenance and operational perspective it does add complexity and the city isn’t set up to handle complexity. Even though people do one thing, it doesn’t mean they can change. For example, stormwater and parks are usually siloed but they have recently been having positive engagements together around waterway management. We did a site visit to parks in the northern suburbs where the Elsieskraal tributary comes

through a park and the stormwater and parks teams worked together. There have been great interactions and practices have been modified. The operational teams have been doing better jobs with engagements. The work has ensured that grey areas where stormwater nor parks know who owns the areas have been managed, the edges have been managed and the hydrology works in such a way that does not kill biodiversity or ecological functioning.

- I am looking at stormwater ponds specifically for multifunctionality; do you think stormwater ponds can be repurposed into multifunctional spaces? Can they actually provide benefits beyond flood control?
- Absolutely, there is no question that ponds can be repurposed to provide multifunctional benefits. It is all in the way we do it, we don't see elements such as ponds as groundwater infrastructure, agricultural land, places for the city to breathe and seep. It's a fundamental part of resilience- adaptability, redundancy, flexibility and having to look multidimensionally.
- Do you think it is worthwhile upgrading stormwater ponds for multifunctionality to fulfil the City of Cape Town's WSC commitment? Are there better ways or infrastructure types with which to do this with?
- What are your experiences with deploying sustainability in day to day practice, what are the challenge in getting this notion to go forward? getting it more entrenched in the city structures?
- Be careful of careful conflating resilience and sustainability. Resilience is dealing with shocks and stresses.
- If areas or ponds have any viability for housing, we have to think about how to set trade-offs up to design for multidimensionality.
- The new Mayor and Mayoral Committee are all about resilience and future planning, there is a resilience directorate now. The resilience strategy was absorbed into the Integrated Development Plan and Municipal Spatial Development Framework.
- The city needs the revenue from water to pay for infrastructure to become resilient.
 - We are setting up a resilience forum for province and city so when a disaster hits you know who needs to be there. It could be disaster management or longer term strategic elements bubbling through. There is now a block on the city scorecard for new projects asking if its resilient. The Executive Directors have resilience linked key performance indicators on their scorecard. These are the reporting mechanisms to build resilience into the city.
- Does the size of a stormwater pond influence its potential for multifunctionality?

WSC planning priorities and criteria

- I have created seven WSC planning priorities based on literature, policy documents and the benchmarking study. I am going to go through each priority, the proposed criteria or dataset and ask for your inputs, comments on the datasets and so on.
- It is a good idea to have alignment with the Cape Town Municipal Spatial Development Framework and Integrated Development Plan as a strategic starting point, it gives you an opportunity to spatialise it. For example, is this pond located in an area that will be developed for something, so connecting the criteria to future planning ambitions, it stacks it up for a budget argument, allows you to use systems thinking and consider how they interact with each other. You can have a couple touchpoints that set the system up, such as are they on a non-motorised transport route, do they intersect with the heritage overlay zones. You have alluded to these touchpoints. Have a look at the heritage policy and the Integrated Development Plan. Make the link to the touchpoints more explicit, such as this pond is 100 m away from a BioNet asset and it thus has a potential to build towards that network.

Flood protection significance

- For flood protection significance I have considered a pond capacity check criterion which takes the difference between pond volume and runoff volume to determine adequacy of ponds to store runoff. Using this method only 4% of the ponds cannot store the runoff volume. Do you have any comments or any other ways to assess flood control significance on a city scale?
- No comment.

Increasing access to blue-green space

- Next is activating urban blue-green spaces, so using ponds for amenity purposes. In my example I have looked at recreation potential to indicate a higher level of potential use of the pond as recreation space by people as they live in close proximity to it.
- In terms of what to measure, which of the following would you prioritise: ponds in areas where people lack access to green space or ponds where people live in close proximity to the space so could use it? Or would you prioritise both?
- In terms of access to ponds for amenity – is walking distance more important or public transport routes for accessing a pond?
- Walking distance to ponds is more important as anyone can walk but public transport costs. The city has a vulnerability mapper which uses socio-economic data and other elements. The Integrated Development Plan will give an indication of the priorities for space in the city; quality public space is a lever, improving poor peoples' is also a lever and links to the

resilience strategy. Use clear spatial targeting based on city policies and data for prioritising. For the ponds, look at co-locating, clustering together and leverage shared assets.

- Regarding security concerns, from a practical perspective should ponds near crime hotspots not be prioritised for amenity as there is more risk and thus people are less likely to use them for amenity? Any other comments?
- How do wet versus dry ponds impact recreation potential?
- Consider active recreation such as a soccer field in the dry ponds and during wet seasons it floods.
- Corridors and chunks are good, where you can't you have islands connected with a corridor there can be migration and movement between islands and bits. From a public space perspective, it's very complicated, just look at Greenville Park, there are parks close by that have different functions – some are for kids versus older people versus teenagers. Use the argument that ponds will improve ecological functioning. Hook it up around non-motorised transport routes to create safer mobility pathways through the city.
- Does pond size have an impact on recreation potential?
- For size look at if you can you get a football pitch in or a mini cricket pitch, active recreational spaces need larger sizes while passive recreational spaces don't. A pocket park is small and intimate and still impactful if beautifully landscaped. It's useful to know what else is in an area before deciding how the space may be best used.

Enhancing biodiversity

- For biodiversity, is habitat size or using ponds to enhance landscape connectivity more important?
- I'm not too sure, small pieces are valuable, consider whether it connects with other spaces and corridors.
- There is a study that was done ranking the city's wetlands, there may be a dataset that you can use.
- How do wet versus dry ponds impact on biodiversity?

Managing water quality

- The next priority is managing water quality, so how can water quality concerns that would limit other functions like amenity and MAR be considered? In my example I've looked at the land cover type in the form of distance to informal settlements, so 36% of the ponds are within 500 m of an informal settlement: Darker green ponds (with higher

criterion scores) are those with relatively longer distances to informal settlements – which indicate more potential for multifunctionality (MAR, biodiversity and amenity) as they would be less constrained by water quality impacts.

- I am going to include Potential Contaminating Activities: informal settlement land cover, industrial land cover, main transport routes, CBD, WWTW, sewer overflow hotspots, are there any others?
- Consider landfill sites and WWTWs. There is also pollution that comes from reticulation infrastructure and illegal dumping.
- Land invasions are always a threat so if there is open or vacant land there is risk is if we don't do something what will the impact be, what is the opportunity cost.

Increasing water re-use

- For MAR potential I have considered six sub criteria of aquifer type and presence, transmissivity, soil type and surficial geology. Any other sub criteria or comments?
- Consider what is the risk to their ongoing availability to supply this function of infiltration and aquifer recharge. Will this space still be available, is there anything to protect it and if it were to be impacted then what then for MAR?

Enhancing cultural and heritage associations with water systems

- Enhancing cultural and heritage associations with water systems, I looked for presence of the ponds in the heritage resources sites from the heritage auditing layer. Any comments? Any other datasets that I could use to see where ponds are near heritage sites?
- Look at the heritage overlay zones; the information richness changes around the city.

Reducing climate change impacts

- Where is the UHI effect more pronounced based on higher land surface temperatures, and prioritising those ponds as BGI provides a cooling effect.
- This is good to include, chat to someone at Climate System Analysis Group as there is a lot of spatial variation, on one day you can have 30 degrees in one part of city and 18 elsewhere.

Education services potential

- Both for education services potential and pond ownership.
- Proximity to schools, community centres and religious institutions.

- The religious angle is an important one, there are groups/apostolic churches which use green spaces.
- Also consider the role in potential food production – someone has mapped agricultural spaces and food gardens, think about colocation of spaces, is there urban agricultural space nearby and can it be absorbed into that work and used to manage it?
- Are there partnerships which will help with maintenance – is it near to friends of groups, would they be willing to adopt a pond?
- It's useful to show the catchment and management boundaries and show where the friends groups and catchment management forums are. Get a list of all of the friends groups including parks. It would be good to have green partnerships/platforms to network them and have better management outcomes.
- Look at non city operational potential, however the water department needs capacity to manage partnerships.

Interview 6

Head: Natural Space Systems: Environmental Planning and Sustainability branch, Environmental Management Department, Spatial Planning and Environment Directorate, CCT.

General multifunctionality and stormwater ponds

- Multifunctionality as a concept is used a lot and emerged as a strategy to make cities water sensitive, liveable, equitable but it is quite visionary – do you think it has value for Cape Town and is it relevant given the basic service delivery and operational challenges the city faces?
- Multifunctionality definitely has value, we need to optimise space rather than use it for a single use. Especially in areas where there is dense settlement, we need to optimise space, if a pond is already there and its part of the infrastructural elements, let's look to see how to best use it for multiple purposes.
- It's good to see criteria on reducing UHI, in vulnerable areas the UHI effect will become an enormous issue.
- The operational challenges are huge – we need to view it as providing multiple services. It is already providing basic service through flood protection, otherwise we would have to provide flood protection services some other way. Basic services are traditionally considered as water, sanitation and waste removal, it's important not to forget the element of having space to recreate and those fundamentals, framing it as providing basic liveability services. We need to reframe basic services to include recreation and liveability.
- In terms of operation, a colleague is facilitating an open space working group to bring

different disciplines and groups together. I gave a presentation at a March 2022 working group meeting on the CCT Green Infrastructure Network (GIN) and finished it off with questions on how to operationalise it and achieve this multi functionality.

- We can't have the management spaces segmented where up to the edge of the pond it is an open space/parks problem and then in the pond it is a stormwater problem. We need different management arrangements around these spaces with a holistic management plan that everyone buys into. Operationally, doing multifunctionality depends on the personalities involved and one has to try and institutionalise working together and set a system in place.
- I am looking at stormwater ponds specifically for multifunctionality; do you think stormwater ponds can be repurposed into multifunctional spaces? Can they actually provide benefits beyond flood control?
- I think it depends on the context of where the pond is. I drove past some ponds in Mitchells Plain that were eutrophic and full of litter. One does need to plan future pond with provisions for space for multi functionality. It also depends on the degree of use or multifunctionality one is wanting to achieve, a small fringe of grass still could be space to sit under a tree but then it would need to be quality space, so it's not always size constrained.
- What are the main challenges to integrating concepts like 'GI' and 'biodiversity' in your day-to-day professional practice?
- We are just at the start of the journey of integrating concepts like 'GI' and 'biodiversity' day to day. We have been going through process of integrating them into policy and bylaws and there has been good uptake with certain people. Some people think it's another layer of hindering development though and going forward we can't put more onerous requirements on what to consider before developments can occur. We are needing to demonstrate its value and educate so people can understand the imperative to look at things differently, for example GI can help with resilience and adaptation to climate change. There is always resistance to the new and different though. The operational framework will be challenging especially when it comes to implementation. For example, we had an initiation meeting for the first 5 liveable urban waterways projects, and we will tackle management, ops and maintenance plans once the projects are implemented. From a decision maker's perspective on implementing GI, if you are given budget and now you are not sure if the outcomes will be successful for GI as you don't have a documented case study or such on whether it (GI) will achieve given outcomes it is difficult to implement GI. Without a clear business case and explicit demonstration of successes it is difficult to motivate for GI. A case in point is a tree related example, I am motivating it from a thermal comfort perspective, not from carbon sequestration perspective, and I'm in planning meetings with the roads department who don't want to plant trees and I don't have the proper business cases to present to motivate for it. There is anecdotal evidence from George's mall in the

CBD, which is much cooler with the trees despite all the concrete, it seems clear to me that we have to put trees.

- However, the operations and maintenance is hard, no-one wants to add on to their workload. We need to think about how to contextualise it in the bigger picture and for this the climate action plan will help.
- (Response to her exact role and day to day work) I'm in the environmental management department in environment planning and sustainability and nowadays my core work is developing and implementing the GIN program. For this we've looked at mapping spaces in the city of selected ecosystem services that we've interrogated through questions, which were given answers through meeting with colleagues. The GIN is in the process of being integrated into the district plans and the Municipal Spatial Development Framework – the GIN is not no to development but how to better develop. If a space is providing infiltration functions or has got cultural activities happening, it's how to maintain these functions within the development and to not lose these ecosystem services. Also looking at where there are opportunities to improve say flood protection. When developing the GIN, we had 23 questions which we posed for each space relating to ecosystem services and we evaluated the spaces. We looked at enhancing corridors for part of it, for example planting trees on road corridors to create connectivity along medians. Another component was a gap analysis on policy, we had certain ones identified and made recommendations for GI principles to be integrated into city policies. There is a draft urban forest which was previously the tree management plan, and it includes the trees in the whole cape area. It now has reference to the GI program and when prioritising areas for tree planting it specifies consulting the GI plan also. The stormwater policies also have GI elements in them to embed the concept of GI across the city so it's not just environmental projects. There are multiple project and actions – I am involved with Liveable urban waterways program and other initiatives like that such as the river ambassador program. It is multifaceted, and we are trying get people into NBS and start with considering smaller scale design.
- For the start of the GIN we worked with the CSIR and used a landcover dataset to assess selected ecosystem services and it was very coarse, we also interrogated the district planning. The GIN work involved dividing the city into squares and from there we mapped open spaces from 2018 aerial photography, with a one-hectare determinant. We engaged with culture and heritage, parks and so on. We all sat at a table and looked at the predefined spaces and applied the questions, which linked to 23 ecosystem services, to each of the spaces. Examples of the questions were if the space in the BioNet, is it accessible to the public and so on. We captured the answers on a spreadsheet, digitised it and developed a GI layer along with 2021 aerial photography.
- We are getting it onto the city map viewer so people can see if a development is in the GIN and what are then the things to think about, it will become part of the application and consultation process for developments. For things like rivers, we had a few key defined

points. For the GIN development we had 58 sessions of half day each and got the best information from the people in the room.

- For district planning we looked at infill sites and some took off as they were serving important cultural initiation practices.
- Stormwater ponds featured in the GIN if they fit into the size criteria (one hectare), some of the questions included does the space have a wetland, seepage, is it a dam, etc.
- The Council for Scientific and Industrial Research recommendations after the initial stage were to have a finer land cover mapping with 5 m pixels.

WSC planning priorities and criteria

- I have created seven WSC planning priorities based on literature, policy documents and the benchmarking study. I am going to go through each priority, the proposed criteria or dataset and ask for your inputs, comments on the datasets and so on.

Flood protection significance

- For flood protection significance I have considered a pond capacity check criterion which takes the difference between pond volume and runoff volume to determine adequacy of ponds to store runoff. Using this method only 4% of the ponds cannot store the runoff volume. Do you have any comments or any other ways to assess flood control significance on a city scale?
- For the GI plan/rating scale you developed, how did you consider the original/primary function of the infrastructure or green space, ensuring the engineering aspects are preserved?
- For the GIN, we had a series of questions on whether to include it or not, our questions were does it assimilate pollutants, does it contribute to water infiltration and does it assist with flood control, we just considered these aspects from a primary functioning/engineering aspect.
- A more natural system would get a good score.

Increasing access to blue-green space

- Next is activating urban blue-green spaces, so using ponds for amenity purposes and I am not specifying or going down to the level of saying the type of amenity. In my example I have looked at recreation potential to indicate a higher level of potential use of the pond as recreation space by people as they live in close proximity to it.
- In terms of what to measure, which of the following would you prioritise: ponds in areas

where people lack access to green space or ponds where people live in close proximity to the space so could use it? Or would you prioritise both?

- On a needs basis, I think its sensible to prioritise it where people lack open space, if an intervention is done we will improve accessibility for a community that doesn't have it, perhaps it may be further away but on balance its more important.
- We might perceive that its best for amenity or recreation, that the community wants something like that but sometimes there are unintended consequences or concerns around a space and that is a consideration.
- In terms of access to ponds for amenity – is walking distance more importance or public transport routes for accessing a pond? Connect to the Non-motorised transport routes?
- Walking distance is more important, there are standards for access that parks and rec use, it may be a useful layer to see where parks are prioritising and what their priorities are. People don't use public transport unless it is for something very attractive and safe such as Greenpoint Urban Park or Wynberg Park. People often don't want to go to more local spaces as they are perceived as crime hotspots and they will rather go to the better parks.
- Regarding security concerns, from a practical perspective should ponds near crime hotspots not be prioritised for amenity as there is more risk and thus people are less likely to use them for amenity? Any other comments?
- If you create quality space people will feel comfortable. Crime is active in certain areas as they are undeveloped, for example the eastern shore of Zeekoevlei in the 2000s was a no go and was neglected but now it has been improved and in turn its safer and attracts more people. It's a catch 22, places are unsafe because they are undeveloped so it's not good to prioritise them but then if they become developed, they will become safer and attract more people.
- How do wet versus dry ponds impact recreation potential?
- With dry ponds the concern is that it will be invaded, but if its actively used for sports then it is activated, and won't necessarily be invaded. Wet ponds come with safety concerns, but humans do like to be around water, it creates an identity for a space.
- Does pond size have an impact on recreation potential in terms of active or passive recreation? Do gender dynamics factor in here as in males need larger space for sports and females smaller space?
- Size is constrained by the environment, so I can't really answer that. If you've got a larger water body with bigger perimeter what does that mean, is it local versus regional ponds.
- Should areas with lower socio-economic statuses be prioritised more to improve the lives of poorer people? Should proximity to more vulnerable people be prioritised more?

Enhancing biodiversity

- I have considered where it intersects with the BioNet, but should it be buffered to consider proximity? For example, if the pond is 500 m away from the BioNet should it still be considered or prioritised?
- Take into account ecological service areas and corridors, look at ponds close to the BioNet area. The city is in the process of rerunning the BioNet and putting buffer areas in with 2021 data, it will include buffering outside of the city boundary and will include the supply dams. If the pond is close to a national park it depends on what is in between and the interface.
- For biodiversity, is habitat size or using ponds to enhance landscape connectivity more important?
- Ponds can be perceived as stepping stones, if you are landscaping the terrestrial component of ponds one can landscape with appropriate species that improve urban green biodiversity.
- How do wet versus dry ponds impact on biodiversity?
- Wet ponds have more potential as you can create habitat for birds and other creatures, a dry pond is a piece of grass, but if one changed it, there is opportunity.
- How does the size impact which ponds should be prioritised in terms of the habitat size they provide?

Managing water quality

- The next priority is managing water quality, so how can water quality concerns that would limit other functions like amenity and MAR be considered? In my example I've looked at the land cover type in the form of distance to informal settlements, so 36% of the ponds are within 500 m of an informal settlement: Darker green ponds (with higher criterion scores) are those with relatively longer distances to informal settlements – which indicate more potential for multifunctionality (MAR, biodiversity and amenity) as they would be less constrained by water quality impacts.
- I am going to include Potential Contaminating Activities: informal settlement land cover, industrial land cover, main transport routes, CBD, WWTW, sewer overflow hotspots, landfill sites are there any others?
- I'm glad you have sewer overflow hotspots. Agricultural runoff is a potential problem from a eutrophication perspective.
- This criterion is worthwhile to consider, there is no point upgrading ponds if the water quality is too bad to provide benefits. You can improve poor water quality with GI, we are doing work to this end in Diepsloot, can you put filter strips to prevent overflow and so on.

Increasing water re-use

- For MAR potential I have considered six sub criteria of aquifer type and presence, transmissivity, soil type and surficial geology. Any other sub criteria or comments?
- This criterion ties up with the land covers around them, be careful with infiltrating polluted stormwater into the aquifer, in those critical areas for MAR there has to be different design considerations.

Enhancing cultural and heritage associations with water systems

- Enhancing cultural and heritage associations with water systems, I looked for presence of the ponds in the heritage resources sites from the heritage auditing layer. Any comments?
- Any other datasets that I could use to see where ponds are near heritage sites?
- In terms of datasets, the city has a culture and heritage resources database on the city map viewer where they have graded heritage resources in terms of grade a b or c. you should take into consideration world heritage site, buffer sites and core sites, this is especially applicable in the Gordons Bay area. If you want to speak to someone specifically for this, talk to my colleague who is involved with the mapping of resources.

Reducing climate change impacts

- Where is the UHI effect more pronounced based on higher land surface temperatures, and prioritising those ponds as GI provides a cooling effect.
- Looking at future in terms of UHI, we have done some modelling. Engage with my colleague as they have done some hazard risk and vulnerability modelling and got the highest heat risk into the future. There was a specific study, a hazard risk and vulnerability project that looked at the projected temperatures that are going to be the highest. The heat risk maps were generated on different aspects. You may be able to get the heat risk maps and shapefiles generated.
- Wet versus dry ponds?

Education services potential

- Both for education services potential and pond ownership.
- Proximity to schools, community centres and religious institutions (friends of groups, catchment management forums).
- It is useful to have a community guardian for some of these spaces, there needs to be an interested resident and institutional use for the spaces. For example, the Zionist churches utilise these spaces.

- There is a dataset on schools, the Department of Education will have a point source layer with schools as dots. There will also be a list of early childhood development facilities and the parks and recreation department have a community centre layer. Speak to my colleague in the community services and health management office.
- Bring in the agricultural element through co-locating?
- The urban design principle is to cluster facilities, if a pond is close by it makes logical sense to have it as an extension of that node.
- The mapping of food was a question in the GIN, if the space was used for agricultural or food production. There has been a bit of work done on it, you may be able to find someone at UCT who has done some mapping.
- Design philosophies are to cluster with other facilities so keep libraries and clinics together so it becomes a node, you could have the ponds as an extension of the nodes.
- Look at the Cape Town District Spatial Development Framework which goes to a district mapping level, the Cape Town Municipal Spatial Development Framework will be too high level and the maps are about statutory issues.

Interview 7

Interim Director, Future Water Institute and Department of Civil Engineering, UCT.

General multifunctionality and stormwater ponds

- Multifunctionality as a concept is used a lot and emerged as a strategy to make cities water sensitive, liveable, equitable but it is quite visionary – do you think it has value for Cape Town and is it relevant given the basic service delivery and operational challenges the city faces?
- It absolutely has value and it's even more relevant across the two cities in one that we have in SA and around our big cities because people in different areas have different perspectives and needs for multifunctionality. The stormwater ponds have a whole lot of different uses and the ways in which people perceive their use is different across spaces, incomes, cultural identities and so on. To allow for a broader view of what a WSC might be, multifunctionality could give us multiple means of achieving that vision through providing different types of functions based on where they are place.
- In stormwater ponds you can't move away from basic functionality, which is localised flood alleviation, so that should never inform the other functions of ponds. It actually restricts what the functions could be as.
- There is a reframing of what basic needs are, but you're never moving away from the flood

alleviation function. We are new on the journey to multifunctionality, we don't know what the basic functionalities in a WSC are. There are many functions of ponds in terms of amenity and biodiversity and ecosystem services but also water quantity control that can be considered basic services. In the context of climate change and resilience, to have a city that copes with future challenges, it's a work in progress of what becomes a basic need and a nice to have.

- I am looking at stormwater ponds specifically for multifunctionality; do you think stormwater ponds can be repurposed into multifunctional spaces? Can they actually provide benefits beyond flood control?
- Yes, they absolutely can be repurposed.

WSC planning priorities and criteria

- I have created seven WSC planning priorities based on literature, policy documents and the benchmarking study. I am going to go through each priority, the proposed criteria or dataset and ask for your inputs, comments on the datasets and so on.
- In the context of the April 2022 Durban floods, how did they get into such trouble. Water quantity in a short time was a problem but one of the stark images and challenges to emerge is around planning and city making and what we do, not just in terms of providing stormwater infrastructure. Its where we place developments and how we place developments. Where vegetation has been removed and the topsoil was cleared was where the flooding was perhaps the worst. Would it help to give more thought to stormwater in the clearing process for those kinds of developments? It made me think there is much more to planning areas within cities at the local scale and how we think about city making.

Increasing access to blue-green space

- Next is activating urban blue-green spaces, so using ponds for amenity purposes and I am not specifying or going down to the level of saying the type of amenity. In my example I have looked at recreation potential to indicate a higher level of potential use of the pond as recreation space by people as they live in close proximity to it.
- In terms of what to measure, which of the following would you prioritise: ponds in areas where people lack access to green space or ponds where people live in close proximity to the space so could use it? Or would you prioritise both?
- Not having any other access to green space would make ponds more attractive for repurposing but at the same time higher population densities with no other green space would mean ponds become more attractive.
- In terms of access to ponds for amenity – is walking distance more importance or public

transport routes for accessing a pond? Connect to the non-motorised transport routes?

- Walking distance, particularly for people needing these amenity spaces, is important.
Public transport for places like green point urban park is perhaps more important because it provides them with a real value. It depends on how much amenity you provide, if the space is particularly beautiful and safe people will use public transport to get there. The smaller ponds may not offer that extent of amenity, so public transport may not be worth peoples' while.
- Regarding security concerns, from a practical perspective should ponds near crime hotspots not be prioritised for amenity as there is more risk and thus people are less likely to use them for amenity? Any other comments?
- It is difficult to include safety and security concerns and rank them in the first stage, so it will depend on the sort of amenity provided. Upgrading a pond into a park may alleviate crime but if it's just a small park pond it may not have material difference on crime. It's a second order criterion – don't prioritise ponds in heavily crime ridden areas.
- How do wet versus dry ponds impact recreation potential?
- For wet and dry ponds there are different forms of amenity based on the two. This will be linked to the income levels discussion. Wet ponds, unless managed well are probably not appropriate in lower income areas because of safety, children drowning risk, pollution and so on. It links to wet ponds having to be in areas where there are a higher level of management or people doing different forms of amenity like sailing.
- For distinguishing between wet and dry you can spend a small amount of time and then make an assumption, most are probably dry anyways. We know which ones are wet, and there are probably not more than 50 wet ponds.
- Does pond size have an impact on recreation potential in terms of active or passive recreation? Do gender dynamics factor in here as in males need larger space for sports and females smaller space?
- Pond size links to how it has been designed and most are oversized for flood alleviation capacity. There may be a sweet spot for size, is it a double soccer pitch, you need a means of delineating the area and keeping it separate from the main part of your pond, so you need it to be bigger than one soccer pitch.
- There may be a second order criteria in terms of gender. If there's a play area for the kids with table chairs and trees for people to gather, women may favour it and size might make difference.
- Should areas with lower socio-economic statuses be prioritised more to improve the lives of poorer people? Should proximity to more vulnerable people be prioritised more?
- This links to the population density and how many people live in nearby areas that don't

already have access to other green spaces. There will be a strong linkage in terms of access to green spaces to socioeconomics. It goes back to green point urban park where people will make a bigger effort to travel to. Those spaces become the gold standard and the flagships. But in general, the amenity function should be prioritised in lower income areas.

- Housing issues? How can green spaces be prioritised when housing is the biggest issue?
- If the pond is in a heavily informal areas, it may have an invasion threat, and do you provide an amenity to prevent it from being invaded? It links to other criteria around available amenity, green space and walking distance.

Enhancing biodiversity

- I have considered where it intersects with the BioNet, but should it be buffered to consider proximity to the BioNet? For example, if the pond is 500 m away from the BioNet should it still be considered or prioritised?
- Yes, buffer the ponds.
- For blue-green cities we are thinking about the network of spaces that can act as biodiversity corridors, if they are going to be doing that to have them buffered is fine.
- For biodiversity, is habitat size or using ponds to enhance landscape connectivity more important?
- Landscape connectivity is the most important. We are picking this up in the literature around green roofs, the roofs are landscape connectors. The pearls in the necklace in the landscape.
- How do wet versus dry ponds impact on biodiversity?
- Each stormwater pond will have a level of wet versus dry, given that they collect stormwater. There may be similar biodiversity considerations. There are often wet patches in the pond in the first place, it depends how you look at it. A dry pond in a specific area could have big impact from vegetation perspective, maybe even more than aquatic. It depends on local context too much to judge biodiversity potential.
- How does the size impact which ponds should be prioritised in terms of the habitat size they provide?

Managing water quality

- The next priority is managing water quality, so how can water quality concerns that would limit other functions like amenity and MAR be considered? In my example I've looked at the land cover type in the form of distance to informal settlements, so 36% of the ponds

are within 500 m of an informal settlement: Darker green ponds (with higher criterion scores) are those with relatively longer distances to informal settlements – which indicate more potential for multifunctionality (MAR, biodiversity and amenity) as they would be less constrained by water quality impacts.

- I am going to include Potential Contaminating Activities: informal settlement land cover, industrial land cover, main transport routes, CBD, WWTW, sewer overflow hotspots, landfill sites are there any others?
- These sound good. Maybe you don't need the CBD, is there anything to defend your choice of the CBD from the literature?
- Water quality constraints are the elephant in the room, we talk about it all the time, but we do not always incorporate it in a meaningful way.
- Think about whether it is stormwater or urban runoff entering the pond? Looking at polluting land covers points to areas that have a higher potential to contaminate runoff and stormwater.
- Does urban runoff enter a stormwater system? Stormwater is produced when it's raining.
- In an informal settlement you get runoff when it's not raining. Enough of our urban runoff enters the stormwater system to include it.
- The water quality constraint is not a dealbreaker, but it is a limiter so it's good to include.
- This criterion could be swung the other way to say these ponds near potentially contaminating activities need to be upgraded in order to treat the water.
- However back to original because of issues of risk, we don't know enough to say we need to upgrade it, so we need to take an approach that considers risk more than opportunity.

Increasing water re-use

- For MAR potential I have considered four indicators of aquifer type and presence, transmissivity, soil type and surficial geology. Any other sub criteria or comments?
- No inputs here.

Enhancing cultural and heritage associations with water systems

- Enhancing cultural and heritage associations with water systems, I looked for presence of the ponds in the heritage resources sites from the heritage auditing layer. Any comments?
- Any other datasets that I could use to see where ponds are near heritage sites?
- This is a good opportunity to bring culture and heritage associations into the picture and conversation.
- Don't buffer these sites because you're working with a heritage site.

Flood protection significance

- For flood protection significance I have considered a pond capacity check criterion which takes the difference between pond volume and runoff volume to determine adequacy of ponds to store runoff. Using this method only 4% of the ponds cannot store the runoff volume. Do you have any comments or any other ways to assess flood control significance on a city scale?
- Should I prioritise ones that are not performing well for upgrading even though it's not for multifunctionality?
- I'm not sure about this as a criterion, it's off to the side.
- Maybe it's not a criterion and rather part of a study site chapter. Perhaps it's a second order criterion.
- Perhaps if it's not performing a flood alleviation purpose you can prioritise it for some form of blue-green spaces within the city to enhance a WSC.

Reducing climate change impacts

- Where is the UHI effect more pronounced based on higher land surface temperatures, and prioritising those ponds as GI provides a cooling effect.
- Wet versus dry ponds?
- This is a good criterion, no other comments.

Education services potential

- Both for education services potential and pond ownership.
- Proximity to schools, community centres and religious institutions, friends of groups and catchment management forums.
- Call it community services link/connection?
- Good point, it's not just teaching in a schoolroom. Look at connections with communities, such as the Edith Stevens education centre.

Appendix G

Table G1a: The datasets used for the final MCA

WSC planning priority	Criterion	Dataset	Date(s)	Type
Enhancing cultural and heritage associations with water systems	Culture and heritage sites	CCT Local Heritage Resources: Grade III (City of Cape Town, 2019h)	2015–2019	Vector – polygons
		CCT Proposed Heritage Protection overlay (City of Cape Town, 2019k)	2015–2019	Vector – polygons
Increasing water re-use	MAR potential	Surficial geology (Water Resources of South Africa 2012 Study (Bailey & Pitman, 2012) and Wright & Jacobs (2016))	2012 2016	Vector – polygons
		Delineated aquifer zones targeted to develop wellfields (City of Cape Town, n.d.-a)	Not specified (Unpublished confidential data file)	Vector – polygons
		Soil permeability (World Agroforestry Centre Landscape Portal, 2021)	2021	Vector – polygons
		Transmissivity (Water Resources of South Africa 2012 Study (Bailey & Pitman, 2012))	2012	Vector – polygons
Reducing the UHI effect	UHI intensity	UHI intensity (Petric <i>et al.</i> , 2019)	2019 (Unpublished data file)	Raster – 100 X 100 m
Enhancing community services connection with water systems	Proximity to schools, community centres and religious	Schools (Department of Basic Education, 2021)	2021	Vector – points
		Community centres (City of Cape Town, 2019e)	2019	Vector – points
		Religious institutions (City of Cape Town, 2019j)	2019	Vector – points
Increasing access to blue-green space	Recreation potential	Park presence (City of Cape Town, 2019i; City of Cape Town, n.d.-c)	2019	Vector – polygons and points
		2011 census data (Statistics South Africa, 2011)	2011	Vector – polygons

Table G1b: The datasets used for the final MCA

WSC planning priority	Criterion	Dataset	Date(s)	Type
Incorporating stormwater quality limitations	Proximity to potential contaminating activities	Landfill sites (City of Cape Town, 2019g)	2019	Vector – points
		WWTWs (City of Cape Town, 2019m)	2019	Vector – points
		Informal settlement land cover (South African National Land-Cover 2020 (Department of Forestry Fisheries and the Environment, 2021))	2020	Raster – 20 x 20m
		Industrial land cover (South African National Land-Cover 2020 (Department of Forestry Fisheries and the Environment, 2021))	2020	Raster – 20 x 20m
		Roads land cover (South African National Land-Cover 2020 (Department of Forestry Fisheries and the Environment, 2021))	2020	Raster – 20 x 20m
Enhancing biodiversity	Wetland status	Prioritisation of City Wetlands (City of Cape Town, 2019d)	2019 (dataset classification information from 2009)	Vector – polygons

Appendix H

Table H1: Stakeholders present at the weighting workshop, names are not disclosed for privacy reasons

Position	Affiliation/title
Associate Professor & Interim Director	Future Water, UCT
Professor	Future Water, UCT
Senior lecturer	Future Water, UCT
PhD candidate	Future Water, UCT
PhD candidate	Future Water, UCT
Landscape Architecture consultant	Landscape Architecture consultancy
Postdoctoral fellow	University of Copenhagen
Principal Professional Officer, Resilience Department	Future Planning and Resilience, City of Cape Town (CCT)
Principal Professional Officer: Decision Support Systems & Data Management, Bulk Water Branch	Water and Sanitation Directorate, CCT
Principal Professional Officer, Catchment Stormwater and River Management – Bulk Services	Water and Sanitation Directorate, CCT
Head: Natural Space Systems: Environmental Planning and Sustainability branch, Environmental Management Department	Spatial Planning and Environment Directorate, CCT
Senior Geospatial Analyst, consultant	Groundwater consultancy
Postdoctoral fellow	Future Water, CCT
MSc student	Future Water, CCT
River management team	Edith Stevens nature reserve, CCT (community group)
Ecological co-ordinator	Recreation and Parks Department, CCT (community group)
Ward Councillor	Ward 75, CCT (community group)
MSc student	Future Water, UCT
Urban Catalytic Investment department	CCT

Evaluating the multi-functional potential of stormwater ponds: planning support for a Water Sensitive City transition in Cape Town, South Africa		
This PhD research uses a Multi-Criteria Analysis as a tool for identifying strategic 'priority' stormwater ponds that offer the highest potential to provide multi-functional benefits, corresponding to seven Water Sensitive City planning priorities		
Jessica Fell PhD student, University of Cape Town Supervisors: Prof Neil Armitage & Dr John Okedi		
Water Sensitive City planning priority	Criterion and attributes	Explanation
Enhancing cultural and heritage associations with water systems	Proximity to culture and heritage resources	Intersection with Grade III heritage resources indicates potential for the pond to contribute to conserving the heritage resource
Increasing water re-use	Managed Aquifer Recharge potential	The ponds require suitable conditions for MAR via surface infiltration
Reducing the Urban Heat Island effect	Average land surface temperatures	The higher the average land surface temperatures, the greater the need for cooling from Blue-Green Infrastructure
Community services connection with water systems	Proximity to schools, community centres and religious institutions	The closer the ponds are to schools, community centres and religious institutions, the more education services reach and pond ownership by surrounding community there can be
Increasing access to blue-green space	Recreation potential - Mean population density in 500m radius of each pond	The higher the population density, the higher the level of potential recreational use by people living with walking distance
	Estimate of residential land use without access to recreation amenities	The more people without access to amenities, the higher the priority to address the 'park poverty'
Incorporating water quality limitations	Proximity to Potential Contaminating Activities (informal settlement, industrial, landfill, WWTW, sewer overflow hotspots)	The further away the pond is from Potential Contaminating Activities, the lower the likelihood for poor water quality impacts to limit other potential functionalities
Enhancing biodiversity	Landscape connectivity metric	The more ponds can enhance landscape connectivity, the better for biodiversity
	Cape Town Biodiversity Network category presence and category	Alignment to the Cape Town Bioregional Plan Policy

2 - RANKING	
order the planning priorities from most to least important	
Water Sensitive City planning priority	Rank order (1 – 7)
Enhancing cultural and heritage associations with water systems	
Increasing water re-use (Managed Aquifer Recharge potential)	
Reducing the Urban Heat Island effect	
Community services connection with water systems	
Increasing access to blue-green space	
Incorporating water quality limitations	
Enhancing biodiversity	

3 - POINT ALLOCATION	
allocate 100 points amongst the planning priorities	
Water Sensitive City planning priority	Points
Enhancing cultural and heritage associations with water systems	
Increasing water re-use (Managed Aquifer Recharge potential)	
Reducing the Urban Heat Island effect	
Community services connection with water systems	
Increasing access to blue-green space	
Incorporating water quality limitations	
Enhancing biodiversity	
	100

Figure H1a: Weighting workshop handout

4 PAIRWISE COMPARISON - compare pairs of criteria with the underlying scale from 1 – 9 to rate preferences			
Water Sensitive City planning priority		more important?	Scale
A	B	A or B	1-9
Enhancing cultural and heritage associations with water systems	Increasing water re-use		
	Reducing Urban Heat Island effect		
	Community services connection		
	Increasing access to blue-green space		
	Incorporating water quality limitations		
	Enhancing biodiversity		
Increasing water re-use	Reducing Urban Heat Island effect		
	Community services connection		
	Increasing access to blue-green space		
	Incorporating water quality limitations		
	Enhancing biodiversity		
Reducing Urban Heat Island effect	Community services connection		
	Increasing access to blue-green space		
	Incorporating water quality limitations		
	Enhancing biodiversity		
Community services connection	Increasing access to blue-green space		
	Incorporating water quality limitations		
	Enhancing biodiversity		
Increasing access to blue-green space	Incorporating water quality limitations		
	Enhancing biodiversity		
Incorporating water quality limitations	Enhancing biodiversity		

Intensity	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favour one element over another
5	Strong importance	Experience and judgement strongly favour one element over another
7	Very strong importance	One element is favoured very strongly over another, its dominance is demonstrated in practice
9	Extreme importance	The evidence favouring one element over another is of the highest possible order of affirmation
2, 4, 6, 8 can be used to express intermediate values		

EXAMPLE: I need a new cellphone and have a list of cellphones to choose between – I need to make the best use of the relevant information available to inform the choice

Criteria (what I value in a cellphone) and weighting (the relative importance of the criteria)

Criteria	Point allocation (100 points)	Ranking
Battery life	35	2
Cost	45	1
Screen size	20	3

Pairwise comparisons				
Criteria		More important?	Scale	Explanation
A	B	A or B	1 - 9	
Battery life	Cost	B	3	As a student, cost is more important but only slightly more than battery life as I have long days working on my thesis
	Screen size	A	4	Given my long days, battery life is more important and in between slightly and strongly favouring it over screen size, which is still of value to me as I read articles on my cellphone
Cost	Screen Size	A	5	Cost is significantly more important than screen size

Figure H1b: Weighting workshop handout