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Sustainable Urban Water Management under a Changing Climate: The Role of Spatial Planning

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Abstract: The provision of a sustainable supply of water is an increasingly difficult task to achieve in many urban environments. This arises because of pressures related to population growth and increased per capita demand for water. Additionally, climate change is impacting the natural cycle of water in many locations, with a significant impact projected for the future. Many scholars advocate ‘sustainable urban water management’ (SUWM) as an approach that can address the root causes of these challenges. Yet the implementation of SUWM and adaptation to climate change in the urban water sector remains limited. This paper argues that spatial planning provides tools and processes that can facilitate the full implementation of SUWM goals, and adaptation to climate change. The potential of spatial planning to achieve SUWM, including sustainable urban water supply management through both supply and demand end initiatives, in light of climate change, is discussed. A framework is developed to consider a broad range of spatial planning interventions that can facilitate adaptation to climate change and SUWM concurrently. The paper provides information and tools to assist water planners achieve SUWM and a well-adapted water sector and urban environment, in an integrated, holistic and comprehensive manner, to meet future water supply needs. Achieving these goals will need collaborative activities across multiple built environment disciplines. Future research activities to advance these goals are outlined.

Keywords: water; spatial planning; climate change; adaptation; urban; sustainable urban water management

1. Introduction

Water is essential for life, and yet there is evidence that we are facing a water crisis [1,2], with recent warnings that we are already experiencing “peak water” [3]. It is argued that in the first part of the twenty first century, changes in population and economic development are likely to be the key influences on water supply-demand balance [4]. Added to this, the impacts of climate change are predicted to undermine the ability of many existing urban water supply systems to meet both the future and present needs of the populations they serve [5,6]. As such, attention to achieving ‘sustainable urban water management’ (SUWM) is necessary. The concept of SUWM is widely discussed and advocated, yet in many instances it is not defined [7]. The literature implies that SUWM seeks to “produce more benefits than traditional approaches” to water management [7] (p. 7151). SUWM has been defined by Gleick as requiring ‘the use of water that supports the ability of human society to endure and flourish into the indefinite future without undermining the integrity of the hydrological cycle or the ecological systems that depend on it’ [8] (p. 574). This implies the consideration of climate change, and the inclusion of both supply and demand side initiatives. In order to achieve this

SUWM goal, new paradigms to water management have been heralded, including concepts such as Integrated Urban Water Management (IUWM) and Water Sensitive Cities [7,9–13]. Yet, despite this, the widespread implementation of SUWM remains elusive [7,14].

In this paper, we argue that spatial planning can play a key role in achieving the implementation of SUWM, and climate change adaptation in the urban water supply sector. The potentially facilitative role of spatial planning in adapting to climate change more broadly has been highlighted by a number of authors (including: [15–20]). While there has been recent analysis of the potential role for spatial planning to facilitate SUWM (e.g., [21]), work has been limited to date. Less attention has been paid to spatial planning's potential role for adaptation to climate change in the urban water supply sector (e.g., [10]). This is despite the fact that land use policy plays a vital role in influencing water use (demand) through planning mechanisms such as control of urban form, density and open space [22], and the acknowledged impact that urban development has on the water quality of the natural environments in which it is located [23].

Spatial planning is distinctly different from the 'planning' traditionally undertaken in the urban water sector. A spatial planning perspective addresses the "activities of economic and service sectors (such as housing, energy, economic development, transport, water, waste, social welfare and health) that have spatial or land use consequences in their wider social and environmental context" [19] (p. 10). It implies an understanding of the natural and environmental resources that underpin human societies, and of the social and economic context within which decisions on land use are made. Spatial planning works with long-term plan horizons (some 20–40 years) [24] and governs development life-times of 60–100 years or more. Hence, these are important considerations for urban water supply planning in light of necessary climate change adaptation.

Additionally, spatial planning has a range of interventions and tools it can implement to achieve goals [24]. As Hopkins [24] details, these include vision/mission statements; strategy planning; agenda/project-based activities; policies, regulations and codes; and design. Spatial planning is often integrated with other forms of governance and management, including legal systems to aid implementation of goals. These can be enacted directly through laws that impact land use, and indirectly through laws that address parallel issues, including the distribution of regulatory authority, and water quality; the exact details and implementation differ between jurisdictions across the world. Aspects of spatial planning are also referred to as land use planning, urban planning, town and country planning, and development control, in some contexts [25].

While acknowledging the significant role water plays in all sectors of society, this paper focuses on urban water supply management rather than on flood control. Our focus is specifically on developed nations. The need for both supply and demand side solutions to achieve SUWM outcomes is recognised. We adopt Mays' [26] (p. 7) definition of urban water supply management to include the management of water sources (e.g., groundwater, surface water, and reuse), transmission, water treatment (e.g., quality), distribution system/s, wastewater collection, wastewater treatment and reuse. We also include the important role of demand management in managing the urban water supply system/s in a sustainable manner. Hence the focus is on ensuring a sustainable supply of water to achieve society's short and long term aims. These include water for domestic and economic purposes, and for social and environmental benefit in these urban areas, such as supporting recreational and ecological landscapes (which may involve, but is not limited to blue and green infrastructure [27,28]), which have an increasingly recognized role in adaptation to climate change [29,30]. Our focus is not on flood risk mitigation across urban areas, yet we recognize that flooding potentially poses a risk to urban water supply and wastewater infrastructure, which we consider in the paper.

The aim of this paper is to demonstrate spatial planning's potential to facilitate SUWM in light of climate change impacts. The method of doing so is outlined in Section 2.

2. Research Approach

In order to demonstrate spatial planning's potential to facilitate SUWM in light of climate change impacts, three broad knowledge domains and their intersections, are addressed, as identified in Figure 1. These are: (1) Sustainable urban water management (the key focus), (2) climate change (the threat to the key focus) adaptation; and (3) spatial planning (the mechanism through which to address/adapt to the key threat). The paper then addresses the topics numbered in Figure 1 sequentially, to present a logical argument.

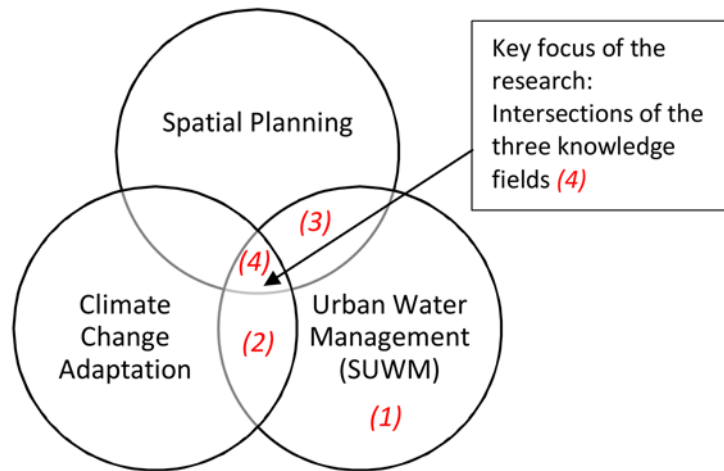


Figure 1. Fields of knowledge explored in this paper (numbers in brackets indicate topics sequentially addressed in this paper).

Given the paper's focus on achieving SUWM, the paper begins with a discussion of the nature of water, its supply, demand, and management (Section 1 of Figure 1). Here, the development of urban water supply management over time is detailed, including discussion of how it has changed, and responded to new circumstances.

Second, climate change adaptation implications and requirements for urban water management (Section 2 of Figure 1) are outlined. Academic literature is drawn upon to do so. A general overview of climate change and adaptation requirements is initially provided, before an overview of projected impacts of climate change on water resources is discussed (Table 1). Examples of activities which can be considered adaptations to climate change for urban water supply are then provided (in Table 2). The examples presented in Table 2 do not claim to represent all urban water adaptations to climate change that are occurring. Rather, they represent a range to illustrate the diversity of adaptations occurring, and their nature.

The examples are illustrated with real world water supply decisions from USA, Australia and UK. They are countries that represent mature stages of development but with different hydrological conditions, governance structures, and water supply management regimes (for instance, privately or publicly-owned water utilities operating at a range of spatial scales). Additionally, they were chosen given the authors have research experience in these countries, and are familiar with the background context of the examples. Each of the examples provided in Table 2 was assessed across adaptation categories: intent, timing, temporal scope, spatial scope, and actor [31,32], which will be further discussed in Section 4.1 of the paper. The assessment of each example's placement in adaptation categories was discussed by the authors given the information at hand about each of the examples (including from academic and grey literature), and the authors' background knowledge of the cases. The authors discussed each example, and came to consensus. At times, the driver for these urban water supply adaptation decisions was not climate change adaptation specifically, or exclusively. This is because policy change occurs in the context of other change including demographic, cultural, and economic change [33–35].

Third, the paper reviews literature regarding the integration of spatial planning and urban water supply management (Section 3 of Figure 1). Factors contributing to the lack of integration

because policy change occurs in the context of other change including demographic, cultural, and economic change [33–35].

Third, the paper reviews literature regarding the integration of spatial planning and urban water supply management (Section 3 of Figure 1). Factors contributing to the lack of integration between spatial planning and water supply planning are identified from the review, and the authors' research and practical experience. The key barriers are presented in Figure 2.

Fourth, the paper addresses the potential of spatial planning to facilitate sustainable urban water management under a changing climate (Section 4 of Figure 1). In order to do so, literature at the intersection of these disciplines is reviewed, and then a framework of spatial planning interventions to achieve climate change adaptation goals in the urban water supply sector is presented. In Table 3, exemplary ways in which spatial planning could potentially achieve climate change adaptation goals in the urban water supply sector through both demand management and supply focused mechanisms are identified. Once again, the examples provided in Table 3 were drawn from academic and grey literature, as well as the authors' experience and knowledge. The examples are for illustrative purposes, and a broad range of examples are drawn upon, that were not necessarily intended to be adaptations to climate change when initiated. We analyse spatial planning's potential through a categorization of types of planning actions put forward in Hurlimann and March [17], drawing on Hopkins [24], at different scales of intervention (both vertical and horizontal) and with different objects of intervention, ranging from the prospective and visionary to the detailed design. Additionally, the authors provide a broad assessment of each type of planning action against the adaptation categories discussed in Section 4.1 of the paper, following the method applied for Table 2. Doing so aids an understanding of the nature of implementing such adaptation actions in practice.

3. The Nature of Water, Its Supply, Demand, and Management

3.1. Water Supply and Demand

Water provides critical support for life, and the environments and societies on which life depends. Its importance is recognised internationally through declarations including the United Nations (UN) International Decade for Action, "Water for Life" 2005–2015 [36], and the Sustainable Development Goals [37]. Both seek to promote the vital importance of water for sustainable development through select programmes and projects. Water is used across all sectors to advance development, including for energy generation, and for agricultural, industrial, recreational and domestic use. Yet, water consumption is dominated by irrigation for agriculture. Recent water statistics indicate that 69 per cent of the world's freshwater is used for irrigation, followed by 19 per cent for industry, and 12 per cent for domestic purposes [38]. While the proportion of water used for industrial and domestic purposes is smaller, their sustainable management is presented with distinctive challenges, such as being located predominantly in urban/near urban areas.

More than fifty per cent of the world's population now lives in urban areas, and is predicted to grow in the decades to come [39]. Urbanization is increasing the demand for high quality water for domestic and industrial use [40] and demand is concentrated in distinct locations. Some of these are in river basins where water supply availability is already sufficiently low to risk disruption to supply. It is estimated that forty one per cent of the world's population live in such areas [41]. Population growth and increases in per capita water use add to pressures on water supplies in some areas. Hence, the supply and management of water in urban areas is of critical importance in many locations. Indeed, throughout the history of human settlements, the availability of water has placed a physical limitation on the expansion of cities [42].

3.2. Urban Water Supply Management and Its Development Over Time

The need to manage urban water supplies on a large scale became apparent with the emergence of urbanization and industrialization, and the necessity for water supply to keep pace with demand for:

drinking, industry, health and sanitation [26]. Measures were taken by governments to secure clean water from distant reservoirs and to provide city-wide sewerage systems [43]. The resulting legacy has been a centralized and technocratic approach to the supply of water—the dominant paradigm for over a century, particularly in developed nations. Indeed, the dominance of this paradigm has been posited as an impediment to the transition to SUWM [9,44].

In many developed countries, the management of water supplies by municipal authorities has continued, with water resources still being a public sector or joint public-private responsibility. In various jurisdictions laws have been developed to facilitate water goals, including the achievement of water sharing between countries and states [45], regulating the quality of water [46] and seeking to integrate water planning and land use planning, for instance in Colorado, USA [47]. The privatization processes of the 1980s in some developed countries, and the continuing privatization pressures in countries of Central and Eastern Europe [48], have led to a loss of integration with other local authority functions such as spatial planning.

The appropriateness of this centralized and infrastructure-intensive approach which dominates the management of water supply and sewage disposal has been questioned over the past two decades [49]. As discussed earlier, there have been numerous proposals to address the shortcomings of the existing paradigm. Fletcher and colleagues [50] identify multiple concepts seeking to address a more sustainable approach to urban water management, ranging from those focusing on urban drainage e.g., Sustainable Urban Drainage Systems (SUDS) (the authors note that some parties omit the ‘urban’ SuDS e.g., in the UK context) to those that look more broadly, including Green Infrastructure (GI), Water Sensitive Urban Design (WSUD), and Integrated Urban Water Management (IUWM) [50]. Fletcher and colleagues found that the way in which urban drainage has been managed has become more holistic and integrated over time. However by integrated, they are not referring to integration with other policy and governance domains (e.g., spatial planning), but rather from broadening from a focus on flood mitigation in the 1980s, to now considering a multitude of factors including aesthetics, water quality, ecosystem benefits, microclimate benefits etc. [50]. The authors also acknowledged the fact that there are many interpretations of the same concept, thus a clear definition of key concepts is advocated [50].

Like SUWM, the concept of IUWM has emerged over the past two decades as an alternative to the traditional paradigm [51]. However, its origins and definition are often contradictory between sources. As characterized by Mitchell [51] IUWM emphasizes demand side management as well as supply-side management, utilization of non-traditional water resources, the concept of fit-for-purpose water quality, and decentralization. In some contexts, IUWM seeks to integrate planning, management and stakeholder participation across institutions and across planning horizons [52]. The implementation of IUWM can be challenging due to the ‘new ground’ being charted, and the lack of precedents to follow [51]. Additionally, it is limited by a number of factors including a hierarchical and market-based governance paradigm, and industry conservatism [53].

At times, IUWM is positioned to seek the integration of water supply planning with spatial planning [44,54], yet there has been little in the way of published research which details how integration with spatial planning might occur, or analyses this in an empirical context. Two recent projects make an advancement to this, including the EU-funded ‘ENMAR’ research [21], and the case of Melbourne in Australia [55–57]. Additionally, guidelines for aspects of IUWM and sustainable water management have been developed [58–60], yet a detailed, holistic and comprehensive analysis of the full potential of spatial planning is lacking.

Despite the efforts of new applications including IUWM to achieve an alternative and more sustainable approach to urban water supply management, there has been limited impact to date. Evidence indicates that water resources are currently over-exploited in many regions of the world. Current patterns of water use are already unsustainable resulting in risks to human welfare, and damage to ecosystems and wetlands [3]. The capacity of spatial planning to facilitate SUWM and achieve IUWM has been explored in a limited manner, hence further research is needed to investigate

this potential. We contend that the difficulties in achieving SUWM are even greater in the context of climate change adaptation, to which our focus now turns.

4. Climate Change Adaptation in the Urban Water Supply Sector

4.1. Climate Change and Adaptation

As detailed by the Intergovernmental Panel on Climate Change (IPCC) [61], since 1750 human activities have greatly increased global atmospheric concentrations of greenhouse gases. This has resulted in significant warming of the earth's atmosphere, and will contribute to further warming in the future. Changes in global climate are anticipated to have significant impacts for current and future generations. Thus, the international community through the UN Framework Convention on Climate Change agrees that action needs to be taken both to mitigate this change, and to adapt to those changes which are unavoidable. The IPCC in its Fifth Assessment Report defines adaptation as

“The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects”. ([62] p. 118)

There are many ways in which adaptation actions have been categorized [31,32]. These include an adaptation action's: (1) *intent or purposefulness* e.g., whether an action is autonomous or planned; (2) *timing* relative to climate stimulus e.g., reactive, concurrent or anticipatory; (3) *temporal scope*, e.g., long term or short term; (4) *spatial scope* localized or widespread; and (5) *actor*—public or private [31,32]. These categories will be utilised later in the paper: to analyse a select number of existing water adaptations; to usefully group barriers identified to the integration of spatial planning with water supply planning; and to consider the potential role of spatial planning in adapting to climate change in the urban water supply sector.

There is still much work to be undertaken to further the progress of knowledge and understanding of adaptation, and to ensure adaptation actions are successful. While evaluation of adaptations has long been discussed [32,33], little consensus exists on how to define successful adaptation [63]. Defining adaptation is difficult because agencies often adapt to a number of different factors concurrently [64], hence a simplistic view, ignorant of unintended consequences, often prevails [65]. Hence greater understanding of climate change adaptation is needed in the context of water supply management, spatial planning and other sectors.

4.2. Climate Change Impacts on Water Resources

The impacts that climate change will have on water resources have received research attention (see for example [5,35,66–69]). Bates et al.'s [5] review for the IPCC concluded that water resources are particularly vulnerable to, and strongly impacted by, climate change. A range of consequences for human societies and ecosystems were identified. The anticipated changes include an increase in precipitation intensity and variability, which will increase the risk of floods and droughts in many areas; additionally, changes to water quality and quantity will be experienced [5]. In Table 1, we present the three key climate change water impacts identified in key sources [5,69] and discuss the implications for urban water supply management and spatial planning. Table 1 is provided to illustrate these impacts only. The extent of implications will vary from location to location, and will be more extensive than the overview provided in Table 1.

The range of climate change impacts to contend with when managing urban water supply is far reaching, including impacts on water needed for waste-water treatment [70]. Climate change might also affect the function and operation of existing water infrastructure (for instance, through exposure of pumping stations or water-treatment plants to flooding). Disruption to water supplies will pose risks to economic production chains and urban food supplies [71], thus having wider impacts. In addition to the direct and indirect impacts of climate change for water resources, it has been argued

that climate change will increase demand for water [69,72,73] an important consideration for water supply management. Hence the challenges for water managers to contend with in a changing climate are on both the supply and demand ends of the spectrum of water supply management. Importantly, Bates et al. [5] reported that climate change problems had not been adequately addressed in water resource management, and contend that current water management practices may not be robust enough to cope with the anticipated impacts of climate change.

Table 1. Key climate change ‘water’ impacts and their implications for urban water supply and spatial planning.

Climate Change ‘Water Related’ Impacts [5,69]	Urban Water Supply Implications [5,69]	Spatial Planning Implications
Increased risk of droughts	<ul style="list-style-type: none"> - Traditional urban water supply systems may not be of sufficient scale to address supply needs - Alternative water supply systems required - Increased demand management initiatives 	<ul style="list-style-type: none"> - Reduce demand for water in new development. - Implement water sensitive urban design strategies: public and private - Limit development in areas identified as at high risk of drought
Risk of increased heat waves/hot days, which will impact demand for water in urban areas, and supply	<ul style="list-style-type: none"> - Increased demand for water during these periods—need to ensure infrastructure and supply is adequate. - Decrease to supply inflows—alternatives needed 	<ul style="list-style-type: none"> - Incorporate blue-green infrastructure, to facilitate urban cooling, and mitigate increased demand for water.
Increased risk of floods, including from sea level rise	<p>Flood damage to critical water infrastructure, including:</p> <ul style="list-style-type: none"> - drinking water supply infrastructure - drinking water quality impacts - wastewater treatment plant infrastructure 	<ul style="list-style-type: none"> - Planning (zoning) for urban water infrastructure to be located outside current and future flood zones. - Planning for future development to be outside current and future flood zones. - Retrofit/action for areas not currently in flood risk area, but will be so in future.

4.3. Climate Change Adaptation in the Urban Water Sector

Until recently, only a limited number of studies investigating adaptation to climate change in the water sector had been published [5], with an increased awareness of the issue in the last decade. Extant studies include: anticipatory assessments, such as of the impact of climate change for demand for water in the UK [73]; the development of a simulation model for water supply planning that incorporates climate change uncertainty in the water stressed city of Phoenix, AZ, USA [10,74]; theoretical contributions to advance understanding of governance of the necessary changes to occur [75,76], analysis of the implications of climate variability on water at the local government level in South Africa [77]; the assessment of the adequacy and extent of existing water planning activities, in England [72]; cases of how particular cities are responding to climate change impacts already experienced on their supply systems, in concert with other change factors [5,78], and case studies of how policy and legal frameworks can facilitate necessary adaptations [79]. Tompkins and colleagues [80] conducted an assessment of adaptation to climate change across six sectors in the UK, two of which included water supply and flood management. Their assessment of over 300 adaptation actions found that most of these were initiated by government, and were in the form of research activities to understand the impacts of climate change. The authors also found that adaptation actions were more likely to have occurred in sectors that had responsibility for significant infrastructure such as the water industry, flooding, and construction. They found that initiatives were predominantly top down, with limited evidence of adaptation actions filtering down to local government level [80].

A number of studies do attempt to take a broad view of climate change adaptation in the water sector [81]. They address such issues as the long-term environmental, economic and social implications of measures to adapt to changes in the supply of and demand for water. However, other studies [82] still take a narrow disciplinary perspective from economics or technology, and overlook the wider sustainability issues or possibility of longer-term maladaptation.

Table 2. Urban water supply adaptation examples—assessed against common climate change adaptation categories [31,32].

Water Adaptation Example	Adaptation Details	Intent (Autonomous/Planned)	Timing (Reactive/Concurrent/Anticipatory)	Temporal Scope (Long Term/Short Term)	Spatial Scope (Localized/Widespread)	Actor (Public/Private)
Large scale augmentation of existing water supply	Construction of a desalination plant to augment existing potable supplies e.g., Tampa Bay, FL, USA [83]	P	R	S	L	Pu
	The use of recycled water to augment existing potable supplies e.g., Orange County, CA, USA, where indirect potable reuse through groundwater recharge is occurring [84].	P	A	L	W	Pu
	Diversification of supply sources e.g., Perth Australia has purposefully augmented supply with non-traditional sources desalinated water, recycled water, managed aquifer replenishment, and catchment management initiatives [85]	P	A	L	W	Pu
Pricing incentives	Metering water use, and charging for water based on consumption e.g., UK policy which seeks to achieve a rate of 80% metering by 2020 in order to meet predicted climate change impacts [86].	P	A	L	W	Pu
	Increasing block tariff (e.g., increase the price of water, the more water is consumed), and increasing the unit price of water under conditions of scarcity e.g., the case of Santa Barbara's drought in the late 1980s early 1990s [87].	P	R	S	L	Pu
	Rebate schemes for residents who install water efficient appliances e.g., as implemented by the New South Wales Government [88] in Australia to address water shortages.	P	A	L	L	Pu
Encouragement of efficient water use	Voluntary behavior change policies e.g., Melbourne's target 155—a program which aimed to reduce water consumption to 155L/p/d at the peak of a significant drought [89].	P	R	S	W	Pu
	Use of spatial planning policies to require water-efficient buildings e.g., in London [90]. Voluntary water efficiency guidelines for development in Inner Melbourne [91].	P	R	S	W	Pu
Informal/small scale water reuse and conservation	Household use of alternative water sources such as collecting water used for one purpose (e.g., showering) and reusing for another (e.g., garden watering). Examples documented by Hurlimann [92] in Melbourne's Millennium drought [93] conditions and under mandated water supply restrictions.	A	R	S	L	Pu & Pr
Investment in small-scale infrastructure	Household and community level installation of alternative water infrastructure such as rainwater tanks, grey-water treatment systems, water sensitive urban design structures [92].	A	C	L	L	Pr
Relocation/resettlement	Population migration due to factors related to water, primarily drought, including twentieth century examples of The Great Plains, USA during the 1930s [94,95]	A & P	R	L	L	Pr
Urban-rural partnerships	Cities work with farmers in river-basins to promote water conservation in agriculture, in order to supplement supplies for urban consumption or for ecological restoration, including examples from the USA and Australia [96]	P	C	S & L	L	Pu & Pr
Integrated approach to water management	Having experienced a significant period of drought linked to climatic change [93], the state of Victoria, Australia has moved towards an Integrated approach to water management [60] to facilitate resilience.	P	A	L	W	Pu

The matrix in Table 2 provides examples of water supply adaptations which can be classified across a range of different adaptation sub-categories. There is potential for some of the examples to fit in multiple categories, but we have placed them where they most logically fit: so, for instance, the 'rebate' example is placed in the 'pricing incentive category,' but would also be appropriately placed in the 'encouragement of efficient water use category'.

Adaptation examples provided include large scale augmentation of existing water supplies with new and often non-traditional sources of water such as recycled and desalinated water. These examples analysed were largely planned, anticipatory (although not always), with wide spatial scope, intended to be long term investments, initiated by public actors. Other adaptation options, such as the use of pricing and behavioural interventions, while planned, were more likely to be reactive, with shorter time frames, yet still initiated by public regulatory institutions (even if implemented by private water companies).

Smaller scale adaptations including informal water reuse and conservation, investment in small scale water efficient infrastructure, and individual decisions to relocate, occur largely privately, autonomously, and in reaction to specific events, with both long and short-term time frames at the local scale. Adaptations based on behavioural activities have been claimed in literature and policy to be too constraining on urban citizens, and only suitable for short term time horizons [85,97,98]. Arnell [99] argues that it is difficult to evaluate the efficacy of the often termed 'softer', demand-side measures, as their performance is difficult to define. This depends on uncertain assumptions about the behaviour of human or environmental responses. Some academic analyses of adaptation in the water sector focus more on supply side options than demand management [64]. However, greater scrutiny of such assessments may be warranted.

An important planning consideration will be how to evaluate the potential success of various adaptation options, with knowledge that maladaptation is a possibility [100]. Dessai and Hulme [64] suggest that under many circumstances capital-intensive resource improvements could be considered robust adaptation options. However, they do question whether these options will be socially, environmentally and economically acceptable. Further research is needed to bridge these diverse considerations. This is necessary given that attempts at adaptation can have unintended consequences [33,101]. For instance, it might be important to avoid adaptation through large scale water infrastructure decisions, because they are often irreversible and shape long-term development paths, and thus the nature of risk within a region [102]. They might also promote maladaptation, and potentially have significant environmental impacts and increase vulnerability or over-dependence on centralized supplies, or reduce incentives to adapt [97]. Despite these significant concerns, there has been limited analysis of the policy and decision context in which urban water supply adaptation decisions are made, or of whether they will be sustainable or successful. Recent water policy analysis in developed nations contexts [55,103–105] has begun to make a contribution to this field.

Large scale infrastructure projects are often expensive, and they are difficult to justify as planned adaptations to future climate change when uncertainty exists about the magnitude, timing and direction of change [102,106]. On the other hand, it could be argued that the long lead times for traditional water infrastructure have meant that water providers are familiar with longer-term thinking and handling uncertainty, and have taken the issue of climate change more seriously than some other utilities [81]. Yet, recent discussions of the rate of climate change impacts on urban water supply in the Australian city of Perth, indicate rapid change has occurred in the past decade and a half [107]. When considering the implementation of the strategies presented in Table 2 and beyond, it will be important to consider the implications of each, including their strengths, weaknesses, benefits, and implications, across social, cultural, environmental and economic aspects. These implications vary between locations and jurisdictions given their unique characteristics. Spatial planning's synoptic capabilities can be beneficially harnessed in this regard.

5. The Integration of Spatial Planning and Urban Water Supply Management

There have been calls made in published literature for the integration of water supply planning with spatial planning [21,22,108,109]. Yet, in other cases both in literature and practice there has been little conscious or explicit integration [11,22,110]. As suggested earlier, spatial planning offers the potential to achieve SUWM, through its distinctly different approach to the planning traditionally undertaken in water supply management. Spatial planning involves the ability to make plans and needs the power to implement these. The force of statutory decision-making powers enables planning agencies at different scales (e.g., national, regional and local) “to establish visions and scenarios for the future, carry out urban projects, write policies, strategize to deal with emergent opportunities and problems, and to design specific aspects in detail” ([17] p. 480). For urban areas, spatial planning can govern the type, location, phasing and urban design of water-using activities and their associated infrastructural needs. Yet, despite these abilities, spatial planning and water supply planning have not been well integrated. We provide some possible explanations for this shortfall in Figure 2, grouped into common adaptation categories.

The dominant driver for each of the barriers to the integration of spatial planning and water supply planning provided in Figure 2 were identified in literature, and discussed by the authors. On this basis, they are grouped into the adaptation categories discussed in Section 3.1. For example, the recent focus on flooding (fluvial, pluvial or coastal) in Europe has been a water-related risk response to recent catastrophic events [111]. We consider the dominant driver here is ‘timing’ in so far that these activities are *reactive* to recent catastrophic events. The grouping of explanations which we provide aids the identification of ways forward to integrating spatial planning and water supply management. For example, this indicates that emergency management could better integrate the expertise and resources of spatial planners and water managers, to think holistically, long term, and in an integrated manner about water issues. The grouping of explanations also aids the identification of adaptation challenges. For example, it will be important to consider how to maintain attention to assure a sustainable supply of water in urban areas in the long term, despite the need to employ resources to respond in both the short and long term, to issues of flooding. Directly connecting the two issues would be beneficial with co-benefits, such as drawing attention to risks of interdependencies [112].

We contend that addressing barriers to the integration of spatial planning and water supply planning, including those identified in Figure 2, would enable spatial planning to play a more significant role in the pursuit of SUWM, particularly in light of the necessity to adapt to climate change.

<i>Intent</i>	
-	Failure of spatial planning to address “whole city” issues, with tendency still to focus on change at the margins, rather than the existing built form [19]
<i>Timing</i>	
-	Focus on flooding (fluvial, pluvial or coastal) as a water-related risk in response to recent catastrophic events [111]
-	Recent emphasis in spatial planning on green and blue infrastructure in urban areas [27,111,113] or on water-sensitive urban design [114,115] with less focus on urban water supply more broadly. This is also evident in the 2017 London Plan [116], compared to the 2011 London Plan [117].
<i>Temporal scope</i>	
-	Different time-scales for water and spatial planning, such as in the EU’s otherwise potentially integrative Water Framework Directive [21]
<i>Spatial scope</i>	
-	Uneven patterns of development, with water resources not yet a significant constraint on planned urban development [118]
-	Disjuncture in scale and governance of activities of spatial planning and water planning, with centralized national, provincial or catchment-scale water planning not coinciding with localized urban or municipal areas [119–121]
<i>Actor</i>	
-	Privatisation leading to either concentration or fragmentation of water suppliers [43]
-	Different and possibly divergent professional and disciplinary backgrounds, institutions, language and culture of: water resources managers and spatial planners [22,43,122], despite the shift (in the Netherlands and UK) to “making space for water” [123], and better integration of water with land use [124]
-	Constraints to expertise and resources e.g., in undertaking quantitative sustainability assessments or Strategic Environmental Assessments of new water resource proposals [21,125,126]

Figure 2. Factors contributing to the lack of integration between water supply planning and spatial planning—grouped into common adaptation categories [31,32].

6. Spatial Planning, Sustainable Urban Water Management and Climate Change Adaptation

As previously mentioned, the potential role spatial planning can play in facilitating sustainable adaptation to climate change in general has been widely acknowledged [15–18,20], along with its more general role in facilitating the reduction or elimination of exposure to incidents or disasters such as flooding and bushfires [127,128]. Spatial planning has been used as a facilitator of adaptation to climate change, but only a limited number of studies have analysed such examples. These studies have found various degrees of success in achieving sustainable or successful adaptation [129–133]. While research has begun to link spatial planning, climate change and water, the focus has predominantly been on flood mitigation and control, rather than urban water supply management [102,134,135].

Climate change adaptation reinforces many of the arguments given above for integrating spatial planning with water supply planning. Spatial planning has familiarity with longer-term horizons, both through the time-frames of spatial plans, and through the life-times (some 60–100 years) of the built development outcomes of plans. It can therefore take future conditions under climate change—however uncertain—into account in making decisions. It is also suggested that spatial planning has an integrative role in addressing social, economic and environmental objectives appropriate to climate change adaptation, including both issues of social equity and ecosystems conservation, and that through this integrative role it can promote good adaptation and avoid maladaptation, such as exacerbating social vulnerability [19]. Planning can act to minimize the conflicts between these objectives, and maximize the benefits of joint action: for instance, urban areas will benefit from the restoration of wetlands in order to sustain the ecosystem services provided by wetlands, such as flood control, water cleansing, and food production [41]. Helping overall water supply to be sustainable, addressing climate change impacts related to heat stress, while achieving ecological and other benefits.

In addition, spatial planning offers the opportunity for integrating climate change mitigation actions (such as energy-efficient development) with adaptation actions (such as water-efficient development). Integrating mitigation and adaptation is particularly important for an energy-intensive resource such as urban water supply [136], which has recently been recognized in water policy in Victoria Australia [137]. It also has the capacity to address issues at different spatial levels (such as national, regional and local), appropriate to the different scales at which adaptation actions need to occur, from broad patterns of settlement location, through urban form and urban design, to individual buildings [138]. Spatial planning's association with democratically-elected local government, and its tradition of widening public participation, also makes it an appropriate locus for awareness-raising [19,139,140]. Hanna et al. [141] also argue that it is at the local level in particular that planners can work across diverse sectors, and through their negotiative role help to align the expectations of different communities, agencies and individuals. Moreover, they suggest that planning can offer the continuity and consistency required in adaptation planning despite possible political or cultural changes—an important factor given the many studies (e.g., [142]) which show that loss of knowledge can be a major problem in sustaining climate change adaptive capacity. Indeed, spatial planning has been the catalyst for many adaptation actions [130,142].

This paper argues that the need to adapt to a changing climate will necessarily change the relationship between the disciplines of spatial planning and urban water supply management. For instance, recent work has employed a simulation model for urban water supply planning in Phoenix, AZ, USA. It finds that the risk of severe water shortage in the future can be reduced substantially by limiting population growth, altering the density of growth, and restricting water use on domestic and commercial properties [22]. Each of these are interventions in which spatial planning has a role to play. In Canada, it has been shown that, in a complex institutional setting, integration of water supply management and land use planning will enhance the capacity of rural communities to manage both current and potential future water shortages [143].

Likewise, for urban adaptation to climate change in Europe, the European Environment Agency (EEA) reports that water scarcity is already a major concern, and this will “place cities in competition for water with a wide variety of other sectors, including agriculture, energy generation and tourism” ([113]

p. 6). The EEA argues for the importance of “establishing strong spatial planning” ([113] p. 7) in addressing water scarcity and droughts, which it identifies as one of three key climate change challenges facing urban areas. Spatial planning often draws upon legal frameworks to institute change, and has this capacity for addressing activities to achieve climate change adaptation and water goals [47,79]. In Table 3 we present a framework which was developed to consider a broad range of spatial planning interventions that can facilitate adaptation to climate change in the urban water sector.

The examples in the table indicate that a range of actions are possible, for which spatial planning can promote the achievement of sustainable urban water management in light of climate change. Table 3 indicates that, the planning interventions identified, were all assessed as being ‘planned’. The majority of the types of interventions were categorized as anticipatory, indicating the advanced time-frame at which planning can act on emerging threats. As such, the timing of interventions was predominantly long term in nature, but conducted on both local and wide spatial scales. The majority of the interventions were assessed as having public actors. Many of the examples provided in Table 3 could be described as a ‘flexible’ and on the demand-side rather than supply side of interventions. Yet both types fall within the scope of spatial planning.

Much of the basis of our argument put forward here is theoretical. However we do acknowledge that there are current challenges to the scope and efficacy of spatial planning, particularly at the regional level. In many contexts, planning is struggling to integrate social and environmental objectives with development decisions in the face of austerity and deregulatory pressures. In some developed countries, planning decision-making powers are being centralized, and the regional tier (an important one for catchment and landscape-scale planning) is being dismantled [144]. Additionally, spatial planning outcomes are not always rational due to political processes involved [145]. Thus, these and other factors which act to challenge spatial planning processes need to be acknowledged and addressed in practice.

Additionally, the most optimal initiatives to implement will vary from location to location depending on local characteristics. Thus, careful analysis of the strengths, weaknesses, viability, and implementation processes for application of initiatives across each planning tool type will be important. It is recommended that adaptation actions across the range of planning interventions detailed in Table 2 are implemented, to achieve integration, wide implementation and most optimal outcomes for climate change adaptation and SUWM. Empirical research to evaluate their effectiveness would be beneficial.

7. Bringing the Themes Together

On the basis of our review of the academic and grey literature in these diverse fields of spatial planning, urban water supply management, and climate change adaptation, and of our analysis of practice, we make the following observations. Firstly, spatial planning has considerable potential to contribute to the achievement of SUWM in the face of climate change adaptation challenges (see Table 3). It provides a range of tools that can help implement actions, extending far beyond the examples provided in Table 3. Secondly, there is an urgent need to research this potential more systematically so that methods of adapting appropriately can be identified, and to learn through extant case studies, and their potential applicability to other contexts.

We acknowledge that climate change adaptation presents additional challenges to the barriers against the integration of spatial planning and urban water resource management identified in Figure 2. There is a growing body of work on adaptation to climate change and the role of spatial planning for dealing with water supply management in terms of flood management, particularly in the case of The Netherlands [146–148], and the UK [43,111,120]. However, attention to its role in adaptation to climate change in the urban water supply sector receives less attention. For instance, the innovative European Union Water Framework Directive does not mention climate change in its requirements on Member States to achieve the objectives of good water status by 2015 [149]. The first attempts at co-ordination between river basin management plans and spatial plans [21] have therefore not needed to address climate change adaptation over the initial plan period.

Table 3. A Framework of spatial planning interventions to achieve climate change adaptation goals in the urban water supply sector *.

Planning Intervention	Potential	Example	Intent (Autonomous/Planned)	Timing (Reactive/Concurrent/Anticipatory)	Temporal Scope (Long/Short Term)	Spatial Scope (Localized/Widespread)	Actor (Public/Private)
Vision/mission statement	To place integrated water management and climate change adaptation as a strategic planning vision.	A vision guiding strategic land use planning in Melbourne: “Integrate urban development and water cycle management to support a resilient and liveable city” [150] (p. 114)	P	A	L	W	Pu
	Aiming for clean and plentiful water	“Respecting nature in how we use water, through (i) reforming our approach to water abstraction; (ii) increasing water supply and incentivising greater water efficiency and less personal use” [151]	P	A	L	W	Pu
Strategy planning	Use of the water foot print [152] as a strategic planning tool	Possibility to be used as a strategic water planning tool demonstrated for the case of South-East Queensland in Australia [153]	P	A & C	L	W	Pu
	Strategic planning to consider economic development, ecosystem functions and social change required to meet future water challenges, including climate change	Integration of climate change adaptation in anticipatory assessment tools such as Strategic Environmental Assessments [126]; Strategies for water supply resilience under a changing climate in the UK [154,155]					
	Greater involvement of spatial planners, and spatial planning knowledge in planning/projecting water supply demand and understanding supply augmentation decision impacts	Catchment scale water and land use planning that acknowledges climate change: e.g., in the UK, Water Resource Management Plans, England and Wales [156]; and in the state of Victoria Australia Sustainable Water Strategies [98,157].					
	Urban-rural partnerships or Payment for Ecosystems Services arrangements between urban municipalities and upstream users	San Diego Water Conservation and Transfer Agreement to compensate farmers for water conservation measures to release water for urban consumption [96]					
Agenda/project-based	Water efficiency requirements for building works and subdivision. Often incorporating WSUD principles. Some projects have been used to showcase new concepts.	The case of the integrated water management provision in planning schemes in the State of Victoria, Australia [158]. Water Sensitive Urban Design in Fig Tree Place in Newcastle, Australia [159]	P	R, C & A	L & S	L & W	Pu & Pr
	Planned urban water conservation and recycling	Examples span many decades and contexts. e.g., New York’s water demand strategy [160], and Water Recycling Plan for Melbourne [161].					
Policy/regulation/code	Control land use in potable water catchments to ensure no threats to water quality or quantity	Guidelines for development in open potable water supply catchments in the State of Victoria Australia [162]. They have since been removed after a change of government. Aim to protect agricultural use of land surrounding catchments in New York to protect water quality—with benefits for food production [163].	P	A	L	W	Pu
	Limit or prohibit certain land use/development in areas of water scarcity, including through laws relating to water and land use	Arizona’s Groundwater Code requires developers to demonstrate a 100-year assured water supply before subdivision [164] since the 1980s. Experience shows developments still get approved while scarcity remains a key issue e.g., Phoenix, AZ, USA [165].					
	Climate change guidance for water supply decision making	Guidelines for assessing the impact of climate change on water supplies in Victoria [166]					
Design	Building design codes to mandate water efficiency	UK Code for Sustainable Homes seeks water efficient developments. To achieve levels 5/6, developments need to reduce per capita consumption to 80 lpd, (English average is 140 lpd [19]). Singapore’s ‘Active, Beautiful, Clean Waters’ Design Guidelines [167]	P	A	L	L & W	Pu

Note: * Categorized by types of planning intervention and assessed against common adaptation categories [31,32].

Recent approaches to achieve SUWM including green and blue infrastructure [168] can achieve enhanced urban environments under a changing climate [169]. These initiatives largely focus on landscape scales, and in public areas, with a focus on stormwater. While these are beneficial, we believe spatial planning can further achieve SUWM through looking at other scales, other aspects of water management, and across other sectors, and to ensure the full implementation of initiatives, in a comprehensive and integrated manner. This is also true of recent IUWM management initiatives [60]. While these will be beneficial to enhance SUWM, further exploration of how these initiatives could be comprehensively embedded through multiple scales and sectors, of action and across the full range of spatial planning tools would be beneficial to achieve optimal outcomes.

While the mainstreaming of adaptation decisions with existing policy domains has been proposed as a desired goal in adaptation case studies [170], it is argued that a better understanding of the process of mainstreaming is needed [149]. Public and political perceptions of climate change are also important determinants of adaptation actions [171]. While world cities such as London and New York [172] are seen to be taking these issues seriously, not all cities are doing so. Reasons could include lack of experienced exposure to serious water shortages, or because climate change has not yet been perceived by decision-makers as posing a risk to water supplies. Vink et al. [148] give an account of the negative implications of the loss of attention to climate change in Dutch water policy-framing. Importantly barriers may not occur in isolation, but in what Moser et al. [142] call “bundles”. That is, a lack of time can be a result of scarce resources, and social resistance to certain adaptation options is influenced by attitudes, worldviews, cultural norms, place attachment, historical investments, and available adaptation options [142] (p. 67).

A number of reports [171,173] have recently been published to identify the conditions for good adaptation practice in cities with respect to sectors such as water resources, and to promote examples of best practice. It is recognized that conditions will vary between countries and between cities, and that some aspects of urban adaptation will necessarily be locally-specific. However, there is little systematic analysis in the academic literature of the factors which might indicate the sustainability of these adaptation options in principle or in practice.

8. Conclusions

The paper has argued that spatial planning can play a facilitative role in adapting to climate change in the urban water supply sector, and in achieving SUWM, yet implementation has been limited to date [11,22,110]. Examples of how this can be put into practice, across a broad range of spatial planning interventions, are detailed in Table 3. Achieving SUWM goals and concurrently adapting to climate change, requires attention to the scales and forms of intervention offered by spatial planning. Spatial planning can provide a flexible and adaptive set of principles and processes. For example, many commentators stress the need to avoid being “locked-in” to major physical or bulky infrastructure projects in order to secure resilience to climate variability and to future climate change [97], spatial planning offers great potential in this regard. In the light of the warnings about the risks and consequences of “peak water” [3], through its deliberative and adaptive processes, spatial planning can attempt to ensure a more sustainable balance between the demands of urban areas, irrigation and ecosystem functions.

Given the broad nature of the topics covered in this paper, there are limitations to the work. Our breadth of scope limits the depth of analysis we can convey here. Moreover, while we focus on urban water management, this is inextricably linked to water supply in other sectors, and to issues such as storm water and flood management (as a potential future source of water supply), the integration of which we do not comprehensively address here. This would be worthy of extended work in future, and is something spatial planning has the capacity to address. The topics covered here require interdisciplinary co-operation—yet the barriers to doing so acknowledged in Figure 2 [22,43,122] must be addressed and overcome. It is through addressing these interdisciplinary challenges that advancements in knowledge and practice can be achieved for sustainability goals [174]. Further

empirical research to expand, apply and test the holistic application of spatial planning interventions in Table 3 in case studies would be beneficial, and to engage a broad range of practitioners and researchers in doing so. It is acknowledged that this integrative practice of spatial planning, will provide opportunities for co-learning, and to address the oft cited science-policy gap [145].

We consider that the development of a framework to guide the assessment and implementation of the sustainability of adaptation decision options in the urban water supply sector would be beneficial—for which spatial planning could play a key facilitative role. Embedding the development of this framework in multiple case study sites will help to progress the achievement of SUWM in the face of necessary adaptation to climate change. Such a framework would go some way to addressing the adaptation needs for the urban water supply sector as identified in this paper.

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