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Article

Utility Value of Water Data for Strategic Planning of Metropolitan Water Supplies

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Abstract: Rapid technological advancements in information communication technologies have enabled water resource data collection at greater spatial and temporal scale. However, this water data is often limited to the purposes of its primary collection, and limits decisions made by stakeholders towards sustainable urban water management. This empirically focused research paper examines how water practitioners involved in strategic planning can capture additional values from integrating different water data. Furthermore, the perception of 22 urban water practitioners across Australia are presented, regarding the importance of and difficulty in using water data for strategic planning, and the necessary steps for achieving integrated water management practices. Interviewees perception revealed gaps in available water resource data (i.e. water quality, ground water, stormwater, and urban water use), and limitations of industry guidelines for operating within existing governance frameworks. Overall, the research highlights the Australian urban water sector's perception of water data's crucial role in representing stakeholders interest; however, changes made in water data's collection are required for an integrated water management approach. Implications for future open water data standard are discussed.

Keywords: water data management; urban water system; strategic planning; integrated water management

1. Introduction

Water data (i.e. quantity, quality, or use) collection has been growing rapidly with the deployment of information communication technologies across the urban water system[1] (UWS) that monitor and capture changes in spatial and temporal scales. Led by research and technological advances (Benedetti et. al 2013), this growth is caused by water authorities shifting focus towards integrated water

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[1] Urban water system is short for urban water infrastructure systems, which is an integration of centralized and decentralized infrastructure systems, for the purposes of water storage, treatment, and reuse in the urban landscape (Urich & Rauch 2014).

management[2] (IWM) approaches to managing the UWS. A recent assessment of the industry's integrated water resource assessment and modelling community found that while rapid advances in 'big data' analytics did generate useful insights, it also required additional investment and motivation for collecting data (Zare et al. 2017). The growth of water data has created a data management problem, where water data is found to be scattered across multiple platforms with varying quality, and is unusable beyond the primary means for which it was collected (Patterson et al. 2017; BOM 2017). The problem is a global priority. The United Nation's High-Level Panel on Water (HLPW) (2016) identified access to water data as one of the foundational requirements for delivering the Water Action Plan, a detailed approach with steps for averting a future global water security crisis.

Water data is recognized as a critical and strategic investment for UWS to realize sustainable urban water management (SUWM) (Walker 2000 cited in BOM 2017). It does so by informing rigorous evidence-based decision making and generating significant financial returns such as significant mitigation of disaster risks; improvements in water use efficiency; and the cost-effective design of water infrastructure (CIE 2015). Consequently, the utility value of water is measured by its use and the outcomes derived[3]. Given the challenges involved in using this data, we focus on understanding how advancements made towards water data collection has facilitated strategic planning of water supplies in UWS?

Use of Water Data for Planning Functions & Instruments in Strategic Planning

Water data underpins a range of integrated urban planning functions and instruments (PFIs[4]) used for supporting an UWS towards SUWM (CRCWSC 2016). A set of the PFIs have been identified by the Global Water Partnership (Figure 1). Where PFI-1 to PFI-3 are challenged by the described water data management issues for UWS stakeholders to effectively evaluate spatial plans and decisions for planning in PFI-4 (Global Water Partnership 2017; Appendix A).

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[2] Integrated Water Management is a process which promotes the coordinated development and management of water, land and related resources in order to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (Global Water Partnerships 2017).

[3] Descriptions of water data types and their use have been covered extensively in multiple industry report and are not covered in this study (e.g. Good Practice Guidelines for Water Data Management by BOM, and Internet of Water: Sharing and Integrating Water Data for Sustainability by the Aspen Institute).

[4] Planning functions and instruments (PFIs) are artefacts of analysis used to support stakeholders through the strategic planning process. Examples include water mass balance modelling, integrated models, public consultation frameworks, compliance guidelines, and more.

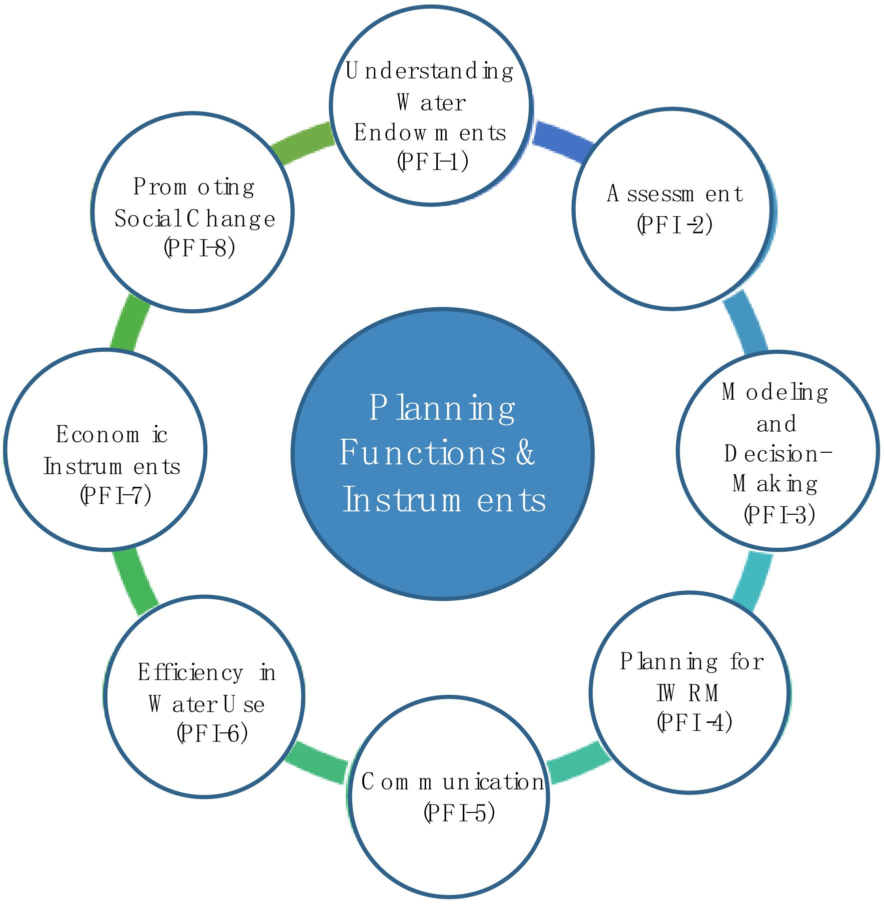

Figure 1. Set of Planning Functions & Instruments in the strategic planning process adapted from Global Water Partnership's Management Instruments.

Before the strategic planning process was introduced, industrialized countries in a traditional socio-technical paradigm assumed its sole objective was to define effective and affordable service provisions (water supply & scheme arrangements) and predictability of the future (scenarios) (Dominguez et al. 2011; Störmer et al. 2009). This meant that completion of the planning process only required stepping through PFI-1 to PFI-4. These assumptions may have worked in the 1970s and 1980s (at least for industrialized countries), but they no longer apply in the face of increased deep uncertainty bought about by climate change, rapid urbanization, socio-economic changes etc. (Dominguez et al. 2011).

A strategic planning process is defined here as a process-oriented way with a set of concepts, processes, and tools to deal with uncertainty and complexity by setting some desirable outcomes (Albrechts 2013; Dominguez et al. 2011). This process addresses a time frame of 20-30 years, due to the nature of the infrastructure sector holding long-time horizons in material structures (i.e. underground piping systems, centralized treatment facilities, etc.) and techno-institutional interdependencies (i.e. regulation, policy, and governance frameworks) (Markard & Truffer 2006; Moaellemi & Malekpour 2018). The goal is to reach a collective understanding between stakeholders about the longer-term priorities of an organization (Schoemaker 1992; Grant 2003). Rather than a fixed objective set by the UWS authorities under the traditional paradigm (i.e. ending in PFI-4), strategic planning sets an outcome that is reflective of UWS stakeholders' diverse perspectives and values to build resilience towards deep uncertainty (i.e. repeating PFI-1 to PFI-8) (Tonn et al. 2000).

The construction of a technical and objective basis for an UWS has shifted from asking the question of "What *will* happen?" to "What *can* happen?" (Mitchell 2004; Malekpour et al. 2013). Where integrated modelling[5] was previously used to answer the former question, research showed the inadequate nature of this with its limited number of scenarios and its lack of consideration for the temporal and spatial dynamics of the UWS (Bankes 1993; Urich & Rauch 2014; Malekpour et al. 2013). Exploratory modelling[6] emerged in recent years as a practical approach in strategic planning by engaging stakeholders, reducing cognitive bias, enabling reflexivity and maturation of stakeholders to drive a set of outcomes shared by stakeholders suitable for the UWS context (Urich & Rauch 2014; Moallemi & Malekpour 2018; de Haan et al. 2016; Malekpour et al. 2013; Truffer et al. 2010).

The communication phase (PFI-5) of strategic planning requires participation from a wide range of public and private UWS stakeholders, such as federal, state, and local government, consultants, utilities, and myriad of water users from community to commercial use. But the participation begins earlier, with contributions made towards PFI-1 to PFI-3 using each stakeholders' water data inputs (each having a different jurisdiction, business function, legislative base, and water data management activities) (BOM 2017). The key innovation here is the increase in utility value of the water data owned by each stakeholder that is bought about through highlighting the synergies between social, urban and water systems (Urich & Rauch 2014; Rauch et al. 2017).

The Cooperative Research Centre for Water Sensitive City (CRCWSC) is an Australian research entity that partners with UWS stakeholders "to revolutionize urban water management in Australia and overseas" (CRCWSC 2016). Their Water Sensitive Cities Index with 20+ UWS case studies established practicality of steering towards a long-term vision of a 'water-sensitive city' and goals in a participatory process with UWS stakeholders, followed by experimentation, learning and reflexivity to test each solution and pathway set forth (Urich & Rauch 2014; CRCWSC 2018). Their success is strengthened by PFIs to communicate the values of integrating social, urban and water systems.

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[5] Integrated modelling mathematically described and quantified the relationship between infrastructure systems under different scenarios. Its focus was on identifying the data and the relationships that cause the most variability (Blumensaat et al. 2009).

[6] Exploratory modelling explores implications of different assumptions and hypotheses with computational experiments. Rather than aiming to predict the future accurately, it generates insight into the system behavior, aiming to identify robust policies that perform well under many future scenarios (Bankes 1993).

We hypothesize that applying available water data in the strategic planning process will enable data sharing among UWS stakeholders, and capture the value of integrating available water data. This is important for justifying investment and action towards enhancing water data value through actions such as the adoption of water data standards, quality management process, and an open data approach (BOM 2017). Similarly, it also offers a potential solution for solving the previously identified water data management problems occurring across global contexts that inhibit SUWM.

Aim of the Study

The study examines the utility value of water data to practitioners involved in strategic planning approaches across Australian metropolitan UWSs. The study uses qualitative semi-structured interviews with selected urban water practitioners to explore the role and perception of water data's value in their individual role and organization. We aim to better understand how water practitioners can enhance their own and overall value of water data available across the UWS. This intrinsic study does not aim to construct a general theory or generic phenomenon that can be applied to quantifying the utility value of water data (Stake 1995).

We recognize that SUWM is only achievable with rigorous evidence-based decision making, which requires a solid information base built on reliable water data. Water data is a vital prerequisite, and increasing its value is critical for achieving SUWM.

The following section (Section 2) describes the research methods adopted to conduct the study; Section 3 reviews the results generated; Section 4 describes the discussion between authors; Section 5 concludes with future research direction and industry opportunities for an open water data standard.

2. Materials and Methods

Grounded Practical Theory (GPT) is adapted from communication practice, and is a variation of the well-tested academic methodology called grounded theory. GPT is applied in this study to described the observed or reported behavior in how water data is utilized in strategic planning into general terms, also known as theoretical reconstruction, to make performed techniques and values in strategic planning explicit. We build systematic theoretical statements inductively from raw observational data captured in interviews through the process of repeated refinement in open coding, conceptual categories, and themes. This is then tested and re-tested in further data collection (Locke, 2001). Consequently, the aim of deploying GPT is to inform good practice by developing theoretical statements that are tested in their practical usefulness and for reflective practice (Koenig et al. 2013; Craig & Tracy 2014). The approach is proven advantageous for capturing the perspectives of a diverse and complex process (El Hussain et al. 2014; Locke 2001).

GPT's practical use in studying the handoff communication procedure between multidisciplinary providers is adapted for this study with different UWS stakeholders (Koenig et al. 2013). Furthermore, a grounded theory methodology has both persisted and been adopted in disciplines beyond its original domain of sociology, and has proven its application in information science and management studies. As such, this qualitative data driven approach fits the needs of our study.

Setting and Participants

Water data is defined in this study by its ability to dimension available water resources and provide an objective basis, which then sets the foundation for a solid fact-based stakeholder consultation (Dijk 2008). We will study the utility value of water data underpinning PFI-1 to PFI-3, which make up the scientific/technical understanding and local knowledge. This is key for realizing SUWM (Mitchell 2005).

Australian metropolitan UWS stakeholders were grouped into five groups based on the jurisdiction of the organization, legislative base, and water data management activities. The groupings are:

(1) **Council** are the local government authority in the metropolitan region who manage the urban environment and represents the local knowledge.
(2) **Government** are the Commonwealth and State government agencies that set the regulatory structure and planning policy for the metropolitan region.
(3) **Utilities** are the water corporations that manage the material infrastructure for supply planning, including both bulkwater suppliers and retailers, who are jointly responsible for producing strategic plans.
(4) **Academic Institutions** are universities and research organizations that support the strategic planning process with their domain expertise.
(5) **Partners** are the service and product providers that are consulted or contracted for completing PFIs.

This study examines the use of water data among water practitioners involved in the initial three PFIs (PFI-1 understanding water endowment; PFI-2 assessment; and PFI-3 modelling and decision-making). We contacted practitioners directly based on co-authors professional network and knowledge of his/her role. Participants were eligible if they had day-to-day experiences operating within and between local and regime levels in the strategic planning process of the UWS, and they had knowledge of the PFIs in scope.

Qualitative Interviews

We conducted individual semi-structured interviews between February and May 2018 with 22 water practitioners. The interviews were structured based on Clarke & Braun (2006)'s recommendation to set a clear scope and share research questions with the interviewees. This limits the parameters for conducting thematic analysis and mitigates the disadvantage of paralyzing researchers seeking an objective truth across a large amount of textual data. The stakeholder grouping was also created to optimally obtain all the potentially available information from each stakeholder group. Table 1 shows the stakeholder groups and the organizations that each stakeholder is from. Encoding was used to anonymously represent stakeholders in the results section of this report. Interviews began with an explanation of the study goals to investigate practitioners' eligibility.

Table 1. Participant's organization in stakeholder grouping and associated encoding.

Organization	Stakeholder Group	Code
University of Western Australia	Academic Institution	A1
Cooperative Research Center for Water Sensitive City	Academic Institution	A2
Local Government Association of Queensland	Council	C1
North Burnett Regional Council	Council	C2
City of Subiaco	Council	C3
Inner West Council	Council	C4
Manningham City Council	Council	C5
Bureau of Meteorology	Government (Commonwealth Agency)	G1
Queensland Department of Natural Resources, Mines and Energy	Government (State Agency)	G2
Victoria Department of Environment, Land, Water, and Planning	Government (State Agency)	G3
South Australia Department for Environment and Water	Government (State Agency)	G4
eWater	Partner (Not-for-profit)	P1
Queensland Water Directorate	Partner (Not-for-profit)	P2
International Business Machine (IBM)	Partner	P3
Aquatic Informatics	Partner	P4
Jacobs	Partner	P5
Water Technology	Partner	P6
Alluvium	Partner	P7
Wave Consulting	Partner	P8
Queensland Urban Utilities (QUU)	Utilities	U1
Water Corporation	Utilities	U2
Water Corporation	Utilities	U3

An indication of questions used are illustrated in Table 2 (full interview guide in Appendix B). We piloted the interview guide in our first three interviews and increased follow-up probes to deep dive into areas of knowledge in water data's use. Interviews lasted approximately 45 min (mean duration = 45:03 min; SD ±17:17 min). 14 out of 22 interviews were audio-recorded with participants' permission, while the rest were captured in Word files due to issues during the interview (e.g. noise, public environment, or recording error). Transcribed interviews resulted in 95 total pages of transcripts (mean length = 4 pages; SD ±0.9 pages).

Table 2. Example Interview Areas and Illustrative Questions from the Semi-Structured Interview Guide

Interview Area	Illustrative Questions
Role of water data in strategic planning	Across the myriad of water data available today, what insights are important to your organization? What are the key performance indicators you're tracking today? What business functionalities in your organization rely on utilizing water data or insights?
PFIs used in strategic planning	Are you familiar with the water indicators supplied by BOM & service providers? How is that information accessed or analyzed? Are you familiar with water mass balance? What other methodologies or frameworks do you use?
Perception of water data's overall utility value in IWM approaches to strategic planning	What is your involvement with integrated water management? What is your perception of its purpose? How does water data help you achieve IWM? If these required insights or data are made readily available to you & your organization, what is your organization's willingness to pay? What are your team's top pain points (challenges) with the water data available to you today?

Grounded Practical Theory Analysis

In order to generate the initial thematic analysis, transcripts were first segmented into question-answer sequences as the basic analytic unit. Next, the semi-structured interview guide was condensed into an individual coding scheme, which provided sensitizing concepts for interpreting participants' responses. The experienced coder listened to the audio recordings (when available) simultaneously with manual coding of the corresponding interview notes and transcripts to discern interactional features contributing to participants' meanings. This included emphatic intonations, pauses, or changes to the participants response in latter parts of the interview. The authors met during the data collection phase to discuss discrepancies found, and were only resolved after reaching consensus. All identified units were coded, and rich segments or quotes were annotated. Secondary data were then collected through literature review to test, corroborate and augment transcript data. Consequently, employing the GPT analysis for conducting an iterative data analysis to systematically develop coding themes to interview areas (Creswell 2007).

Guest et al (2017) found that 94% of all high frequency themes and categories are identified in the first six interviews. After 22 interviews, we found that practitioners had similar interpretations of the insufficiency of data quality and data availability on types of water resources. Review of the initial thematic analysis confirmed the focus of the interviews were valid for answering the research question, how advancements made towards water data collection has facilitated strategic planning of water supplies in UWS? The authors then conducted selective coding[7] across all the interview areas to develop the theoretical response to the research question.

3. Results

3.1. Demographic Characteristics of the Sample

22 Australian water practitioners were interviewed out of the 40 identified to be in strategic planning roles across the authors' network and knowledge of work. The most common reasons provided for non-participation were insufficient experience in strategic planning of water supplies (n = 2), or did not respond to interview request (n = 16). The list below shows the percentage of each stakeholder group from largest to smallest in the interview sample.

- Partner: 36% (n = 8)
- Council: 23% (n = 5)
- Government: 18% (n = 4)
- Utilities: 14% (n = 3)
- Academic Institutions: 9% (n = 2)

3.2. Thematic Analysis

Thematic analyses is intentional in being able to move beyond counting the explicit words and phrases, with a focus on identifying and describing implicit and explicit ideas in the qualitative data to form themes (Guest 2012). A series of four themes were identified and re-tested through a literature review to validate its applicability and reduce bias. They are captured in Table 3 and explained in the subsequent sections. In particular, the gaps in data across water resources to model effectively, was found to have the highest frequency across interviews. The theme was then summarized into a preliminary theoretical response in Table 3 before re-testing with literature review. The focus of which will inform the discussion for capturing water data's utility value in strategic planning and aim to answer the research question.

Table 3. Thematic responses to interview question area.

Interview Area	Selective-Coding Themes	Theoretical Response
Practitioner perception of water data's current utility value in IWM approaches to strategic planning	1. Gaps in data across water resources to model effectively; 2. Contextual & relational data sharing are needed; 3. Inform integration of water supply options in the context; 4. Political biases to modelling;	Major data gaps in water cycle management (notably groundwater, stormwater, and urban water use of non-traditional supplies) are barriers for effective modelling and facilitation of an integrated approach to sustainable urban water management

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[7] Selective coding is a process where the coder treats the various code clusters in a selective fashion, interprets how they relate and the story they tell, to create a set of relational statements

3.2.1. Selective Coding-Themes

Despite agreement on the global aim for achieving SUWM, and the need for resolving the water data management issue, the development of UWS modelling and water-based metabolism models remain unable to make use of the collected and available water data. However, outcomes in a UWS cannot be sufficiently answered with only water data. Studies in theory and case studies applying integrated models found sustainability type criteria to be critical for capturing impacts of water supply intervention strategies across the UWS (Lai et al. 2008; Behzadian & Kapelan 2015).

Interviewee's were then asked about adopting an IWM's approach, which is inclusive of sustainability criteria beyond conventional water management, to evaluate practitioners' use of water data for strategic planning. The thematic responses are mapped across different stakeholder groups in Table 4.

Table 4. Mapping of stakeholder responses to interview questions related to perception of water data's overall utility value in IWM approaches to strategic planning

The use of water data in IWM approaches mean…	Academic Institutions	City Councils	Government	Partners	Utilities
Gaps exist in data across water resources to model effectively	A1	C1 - C2 - C3	G1 - G2 - G3	P5 - P6 - P8	U2
Contextual & relational data sharing are needed	A2	C4 - C5		P1 - P7	
Integration of water supply options in the context			G4	P3	U3
Political biases to modelling				P2 - P4	U1

A significant majority of interviewees indicated that there are still large gaps in water data for practitioners to model effectively for an IWM approach (50%). The response is also represented across all stakeholder groups. It was found that each UWS stakeholders' application of water data involved the use of PFIs described in Figure 1. Different PFIs were mentioned by interviewees, and were interpreted as those under Modelling and Decision Making (PFI-3). From custom in-house modelling with Excel, to industry softwares such as MUSIC[8] or web applications, the PFIs applied water data to achieve the specific outcomes sought after in the strategic planning process in the given UWS context. Additional barriers included the lack of contextual and relational data necessary to achieve sustainability outcomes for the UWS (23%), and political biases that influence the models' interpretation (14%). On the contrary, there are also interviewees who understood an IWM approach as the integration of water supply options to meet demand at minimal cost (13%). Consequently, interviewee responses reveal that rapid advancements in data collection for the industry are still insufficient for strategic

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[8] Model for Urban Stormwater Improvement Conceptualisation (MUSIC) is the industry standard modelling tool for "both simple and highly complex urban stormwater systems using water sensitive urban design. It can simulate urban stormwater systems ranging from a suburban block up to a whole suburb or town" (eWater 2012), and is used as a decision-making aid.

planning of an UWS to address the sustainability and integration criteria of an IWM approach.

> “But there’s a huge gap on what data needs to be captured” (C1)
>
> “Perception is that we have the data and its easy. We started scoping the modelling a year ago but still struggle to get it done. Trying to do a long time.” (G3)
>
> "People are looking at it from a piece meal fashion. Specific answer they wanted for a report. But there’s no integrated approach.” (U2)
>
> “Urban systems – classic one is we don’t know how people are using rainwater harvesting tanks don’t have data. If we really want to talk about decentralized sources then we really need to start monitoring them.” (P5)
>
> "Data access – water quality is the problem. Still a large challenge.” (G2)
>
> "Modelling doesn’t always take into the unique context – and use of groundwater – Long dry periods and the necessary precipitation.” (C3)
>
> "The [developers’ environmental impact assessment] report is handed to a government agency – these reports are available but not the data.” (A1)
>
> “Key thing is understanding the residual groundwater respond to urbanization. Don’t have the data on that. Does the groundwater goes up or goes down? No one can agree on this.” (A1)
>
> “Stormwater indicator – missing as a gap. Management of the stormwater then are based on best practices rather than data supplied via the indicators.” (C4)
>
> “The data on dam heights and river levels is really good at giving the community on whether or not there’s droughts/flood issues coming up. But does not translate to modelling, there’s a lack of predictability under changes / scenario planning.” (P7)
>
> “Massive gap in water quality data, it’s really quite old…Contemporary data shows that the old data is wrong.” (P6)

3.2.2. Decoding Theme: Gaps exist in data across water resources to model effectively

Across the four themes, the theme on gaps of water data passed the threshold set by Guest et al (2017) to be a high frequency theme, and was later discussed by the authors to be a useful insight to the research aim. The most commonly heard data gaps were in stormwater, urban water use, water quality, and groundwater data from the interviewees response above. Beyond the integration of data on the water resources in the UWS, sufficient availability of spatial data is also a prerequisite for good model performance (Benedetti et al. 2013). Interviewees seem to agree as they suggested that availability of water data across different spatial and temporal scales is critical for strategic planning in water supplies for UWS.

> "Temporal scales and spatial scales. The two are key factors that they are grappling with.” (P8)
>
> “Long time for programming and processing data – but when you get a different data sets, and without a tool to process (gets more complex with GIS and spatial with overlays of information and intersection points). Being able to have ways to process the information quickly.” (C5)
>
> “There’s never enough data. There’s always gaps for more information. Whether that is at the finer spatial or finer temporal scales. Always trying to get more information. The challenge is what we do with what we got. (P7)

Interviewees also suggested that for many UWS stakeholders, the responsibility for monitoring such non-conventional water data is not clear. While there are state-wide water data portals made available to UWS stakeholders to improve governance of the water assets, they are not necessarily standardized across Australia.

> “Integrating the two different water supplies – there’s no guidelines for that information and the clear understanding of them. Led by water authorities themselves (bulkwater suppliers). Part of their system. If they’re not involved then it’s very hard.” (P8)
>
> “Streamflow data from own streamflow sensor network – WINS – available to Victoria (partner with other organizations).” (G3)
>
> Western Australia has something called the water information repository – WRI – and this is not available in other states. We frequently access but it’s not found in other states, and it’s very frustrating to not be able to find alternatives… Incredible powerful tool that revolutionized how we work with water” (A1)
>
> “The use of spatial information and the availability of the spatial information – soil & land-use, vegetation, collected by agency but not readily available. Needs interpretation and no responsible agencies for doing it.” (P7)

With IWM’s sustainability criteria in mind, we were not able to find a PFI in literature that is able to evaluate or compare a comprehensive list of water supply options (e.g. surface water, ground water, desalinated water, recycled water, rainwater, stormwater, greywater) (Rathnayaka et al. 2016). Rather, researchers recommend that relevant information, data monitoring, and findings on this topic are necessary to support an IWM approach to PFIs (Truffer et al. 2010; Rathnayaka et al. 2016). In the absence of a suitable PFI, interviewees made references to national and state guidelines such as Australian Rainfall Runoff (ARR) that guide their use of water data. In ARR’s latest revision in 2016, the authors highlight the big opportunity to enhance understanding in PFIs for utilizing water data compared to the 1987 version (Nathan & Weinmann 2016). Interviewees explained that these gaps in water data resources are often projected with models, rather than collecting them due to the cost of data collecting, and difficulty of data sharing in the strategic planning process.

> “The Australian Rainfall Report concludes that there’s not enough urban water data.” (P5)
>
> “Australian Rainfall Runoff – software (patch update) now is being developed where you can pick up series of design storm data. …Urban water chapter – the industry relied on this for the last 30 years.” (C5)
>
> "An area [modelling with water data] that needs a fair bit of work. A lot of modelling is done for the modelling sake, rather than gathering insights for [missing data]." (P7)
>
> "But the data can be quite construed [through modelling]. Overall data sharing is not very fluid – can be quite difficult. The data needs to be peer reviewed and measured." (C4)
>
> “Not a lot of sharing of data across agencies – fairly superficial. At least in the council space – more conversation on that we need to be more sharing information – on GIS data." (C5)

Interviewees gave different responses for their willingness to purchase the data required to complete the PFIs. One interviewee described the influence of politics and inherited schemes as limitations even if data was made available. An interviewee from the Partner stakeholder group explained that the water data should be made free as it should be captured by government. In contrast, an interviewee from the Government stakeholder group believes that the role of capturing these data can be owned by private organizations. Yet a discussion paper among water managers and regulators in the U.S. advocated instead for a nonprofit organization to be the provider of water data, acting as the backbone organization for capturing the water data from data producers (Patterson et al. 2017). There is much debate on this subject, and practitioners are still seeking answers for ownership on the growing amount of water data collected to fit the missing pieces in the PFIs used during the strategic planning of UWS.

> "Will they be able to change anything in the business (benefit) to offset the cost of the information (cost). For example, economics can't buy more water – locked in and can't do anything about it due to political schemes." (C2)
>
> "[Depending on the client, some are] not willing to spend a cent on the data, there's a risk….Water space data that is purchasable: Healthy Land & Water – collects water quality data – ring them up and buy their data. We purchase the data, bill it into the budget." (P6)
>
> "Data collection should be the role of government agencies. Largely to insure the independence and reliability of that data. Reasonable amount of experience in the UK where a lot of the data is done on a fee for service model, [but] it hinders the analysis and assessment of the water industry. Since industry is simply not able to afford and therefore have to use lower quality data. Where information is collected under public funds, the highest quality of the information should be used." (P7)
>
> "The way it's set up right now is that the information gets developed when the need arises. Up till now it's been done on the basis where government does the research, or private proponent will do the research. There might be a time where water is seen as a source for economic development, then there might be a potential for government and private organizations paying for that information." (G4)

In addition to the gaps in available data of non-conventional water resources, interviewees explained other barriers for achieving SUWM. This includes insufficient tools & capacity, lack of direction from regulators, and use of non-water data such as social media data to better understand the UWS context, to name a few.

> "Models themselves cause a lot of problems. Don't have the right modelling tools." (P6)
>
> "The gaps are not in the water data, but it's in where the water regulators are heading. A bit fearful of the targets set up by the regulators, which will seriously change the parameters." (C2)
>
> There are other social factors – such as Facebook and social media sites. That has an influence on the water utility itself. There hasn't been enough exploration on the external." (C1)
>
> "Time and resources for councils to actually sit down to use the data. Most of the time is spent making sure the water safe. Instead of sitting back to evaluate improvement opportunities." (P2)
>
> "There are definite gaps in modelling skillsets across Australia. Some councils have a modelling team, and there are obvious gaps in modelling skills & gaps." (C4)

4. Discussion

The following explores our findings as they apply to practitioners involved in strategic planning of UWS, before interpreting them for the development of an open water data standard as advocated by BOM. We then provide a brief reflection on the methodological strengths and weaknesses of this study.

4.1. Understanding the impact of data gaps for open water data stanards

Water data is foundational to PFIs in the strategic planning process, and sets up the technical understanding and local knowledge for which UWS stakeholders can achieve SUWM. Our empirical analysis suggests that data gaps in both conventional sources (i.e. water quality and groundwater) and non-conventional sources (i.e. stormwater and urban water use) remain missing pieces for strategic planning in UWS. Beyond the water data gaps, there is also the requirement for more spatial and temporal data associated with water resources in order to underpin the PFIs.

We heard from the interviewees that these gaps differ across Australia, and where it is unknown, are often informed by either government guidelines or additional modelling by local experts. There is also a difference in opinion around which organizational entity should be fulfilling these gaps. In Australia, under 2008 Commonwealth legislated Water Act, the Bureau of Meteorology (BOM) holds a range of responsibilities that includes collecting and publishing water information (CIE 2015). However, rising complexity in user expectations (i.e. user-centric format or temporal and spatial scale of water data) has led to a spiraling technical debt and even introduces system fragility (BOM 2016). In the face of these growing costs, BOM's (2016) report on the current state of data availability concludes that open data is an area that is still being defined to facilitate the consistent treatment across both government and users of data.

This study will form an opinion over the debate on open water data standards. An interview with BOM, described their responsibility as "we work with the industry to understand their information needs, and provide products and services to meet those needs. That's a broader picture of industry (cross-sectoral) – policy, strategic planning, operations. (G1)" Yet, a comparison of this study's participant organizations against BOM's mandated list of organization to provide water information too, found five out of the eleven groups described by BOM missing. They are listed below:

- Other agencies of the Commonwealth or a State
- Hydroelectricity generators
- Rural water utilities
- Catchment Management Authorities and others
- Providers of water information for flood forecasting and warning

Similarly, the BOM's list does not include the academic institutions (n=2) and partners (n=8) interviewed in this study. Therefore this study provides the input of practitioners beyond BOM's regulatory oversight to help shape future open water standards. We discuss the four water data gaps identified below, and its impact on open water data standards.

Water quality data

Water quality data was described by intervieews to be old (P6) or not reliable enough (G2) for the PFIs used. The data is collected by councils' legislative responsibility for meeting standards published in The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000 Guidelines) (C3). However, another interviewee also described that this data could be accessed by engaging with academic institutions, who collects much of the water quality data (A1). We can infer that there is an implicit understanding on the importance of water quality data, and there is an opportunity to involve academic institutions in developing open water data access.

Groundwater data

Groundwater data was described by those in states (Western Australia and South Australia) where its availability and quality are relied upon for the UWS's long-term water supplies. In these states, the data are considered sufficient and useful to strategic planning practitioners. This can be seen in the comment made by an academic institution's interviewee on WA's water, "incredibly powerful tool that revolutionized how we work with water". This is likely due to the investments made by local state government to set data availability standards, including the ability to download spatial data (Government of Western Australia n.d.). We can infer that the data standards set by these leading state agencies can be applied to other states to elevate the availability of groundwater data for strategic planning.

On the other hand, the methodology for applying groundwater data for strategic planning can be improved. It was mentioned that water mass balancing modelling, a PFI-1 for Understanding Water's Endowment, does not take into consideration groundwater's infiltration beyond the boundary (A2). Instead availability of groundwater for strategic planning is informed by the state government agency, as an Utilities interviewee explained "modelling is using groundwater allocation, dam storage levels, and supplied production of desalination" (U2). We can infer that the state government agency has an important role in setting the standard of groundwater data, and its efforts seen in some states can be applied to others in the development of a national open water data standard.

Stormwater data

Stormwater or runoff data available for strategic planning is a gap that was highlighted by an interviewee in City Council (C4). And another interviewee agreed on the need for this data as "more information on those [quality of stormwater and receiving bodies] will really help target the actions" (C3). The use of this data is clear for council, as they are "trying to capture data on stormwater systems, and mapping all the stormwater drains in the city to better understand what's going on, to discover further harvesting opportunities" (C4). Utilities also would like to utilize this information to inform the UWS water outlook, "integrating the traditional water supply right from the source to areas of things like demand as well as alternative sources (stormwater harvesting) and various issues that relate to water quality" (U3).

Despite the known importance of stormwater water, a council described that they have "no capacity to undertake modelling" (C3) even if the data was made available. A partner commented that even though there is "more information out there for use, managing, or impact of stormwater – … we're still not measuring it. Always modelling for it almost every time" (P5). Therefore we can infer that an open water data policy should seek to fill the stormwater data gap through enhanced measurement of data, rather than outputs of modelling PFIs such as MUSIC.

Urban water use

Urban water use in UWSs include a myriad of decentralized sources of water supply including rainwater harvesting, and recycled water. The Australian Rainfall and Runoff's new revision in 2016 is a national guideline and reference for Australian engineers, and covers both the urban water data available today and across the state since its first release in 1987. However, the report does not include wording related to open water data standards. We recommend that descriptions of an open water data standard should be updated in its ongoing revisions. This would leverage the guideline's national prominence among water practitioners and enable greater data sharing. The ambiguity of the description in urban water use data is intentional by the authors and should allow for the flexibility to add new urban water resources made possible through changes to existing socio-technological paradigms in the UWS context.

4.2. Enhancing Australia's open water data standards

Advocacy for filling the data gaps assumes that the missing data could be used to support stakeholders in providing their perspectives and eliciting their interests and preferences in the UWS (Delibašić et al. 2015). BOM's legislative authority is both positioned, and aspires to develop a world-leading approach to public data provision that reflects clear and detailed policy advice to agencies (BOM n.d.). The BOM publication, Good Practices Guidelines for Water Data Management Policy (2017) reflects the action taken to fulfill the very same aspiration.

Our study complements these good practice water data guideline by seeking to answer how the rapid growth of water data collection has facilitated the strategic planning process to drive added synergistic value in UWS data. The data gaps identified included water quality, groundwater, stormwater, and urban water use.

Our study employed GPT to not only identify the selective-coding themes through interviews, but further validated its results through a literature review. Grounded by this approach, we infer the following key points:

- Academic institutions and partners should be able to contribute their data towards the open water data standards, supporting data gaps where it is lacking or not-trusted.
- Stormwater data are to be prioritized in its collection given its use case rather than continously applying more modelled data.
- State government agencies should set standards for groundwater data, leading examples can be seen in Western Australia Department of Water and Environmental Regulation's Water Information Reporting data portal.
- The ongoing revisions to ARR 2016 edition should include the description of an open water data standard to increase adoption of data sharing among water practitioners.

4.3. Methodological reflections

The GPT applied is an adapted grounded theory approach that proposes a theoretical framework or response towards a contested topic. The findings are made stronger through the re-testing of its themes and theoretical framework with additional literature review collected. The weakness of this approach is a tendency for biases that stem from the researchers' interpretation of the data captured in interviews, and its synthesis. The weakness of the synthesis is the lack of sensitivity analysis done in transfering themes and concepts between situations. In addition, our research scope were limited to 3 out of all 8 PFIs based on time and resources available (i.e. one principle interviewer that could travel and interview), and the three PFIs were also identified in literature review to depend on water data and practitioners' interpretation. We attempted to preserve the context and allow for the transfer of responses through the selection of water practitioners involved in strategic planning. We also provided structured summaries of our study detailing aims, methods, and setting and sample. This allowed the readers of our study to be able to judge for themselves whether or not the study's review was similar to their own.

Our chosen method means that we cannot say whether or not the water data gaps that were identified applies to all uses of water, nor whether our inferred findings are practical and applicable towards an Australia open water data standards. However, we can say with some confidence which water data gaps are likely to be important for capturing additional value from the integration of existing water data. This can enhance the overall utility value of an open water data standard.

5. Conclusions

The aim of the study was to answer the following research question:

- How have advancements made towards water data collection facilitated strategic planning of metropolitan water supplies?

We characterized the need for solving the ongoing water data management problem for making the transition from traditional to strategic planning approaches We employed the GPT methodology adapted from Koenig et al. (2013) to identify the methods for enhancing water data owned and available to different UWS stakeholders. In doing so we found:

- Current debates on open water data standards should fulfill data gaps on the collection of water quality, groundwater, stormwater, and urban water use at greater spatial scales for UWS stakeholders to enhance the value of available water data;
- BOM's regulatory oversight of water data collection should include a broader set of UWS stakeholders, rather than only to those identified in the Water Act 2008;
- Stormwater data is a priority area for collection given its clear use case among UWS stakeholders, rather than modelled data;
- Existing and leading data standards by state government agencies, notably WA's groundwater standards can be advocated for application in other states;
- ARR & similar industry supported national guidelines should include discussions on open water data standards to increase practitioners' awareness of the value in sharing water data.

Future research on case studies of open water data standards led by the national government authority will define tangible value for data sharing's role in sustainable urban water management. This research should be taken in a systematic manner with repeated studies across different social, political, environmental, and economical nations.

Fulfilled data gaps for a useful open water data standard with a focus on strategic planning process should address some concerns raised in interviews and literature. Further research is still required to understand whether the specified data gaps are a consequence of individual or organizational-scale data collection failures before appropriate remedial guidance can be given. UWS water data is growing rapidly, and its crucial role in robust decision-making means an IWM approach can strengthen decision-making under deep uncertainty. Ongoing challenges in the water industry will thus require a shared understanding built on water data, collected and synthesized for PFIs, to maximize the economic, social welfare and sustainability of UWS towards SUWM.

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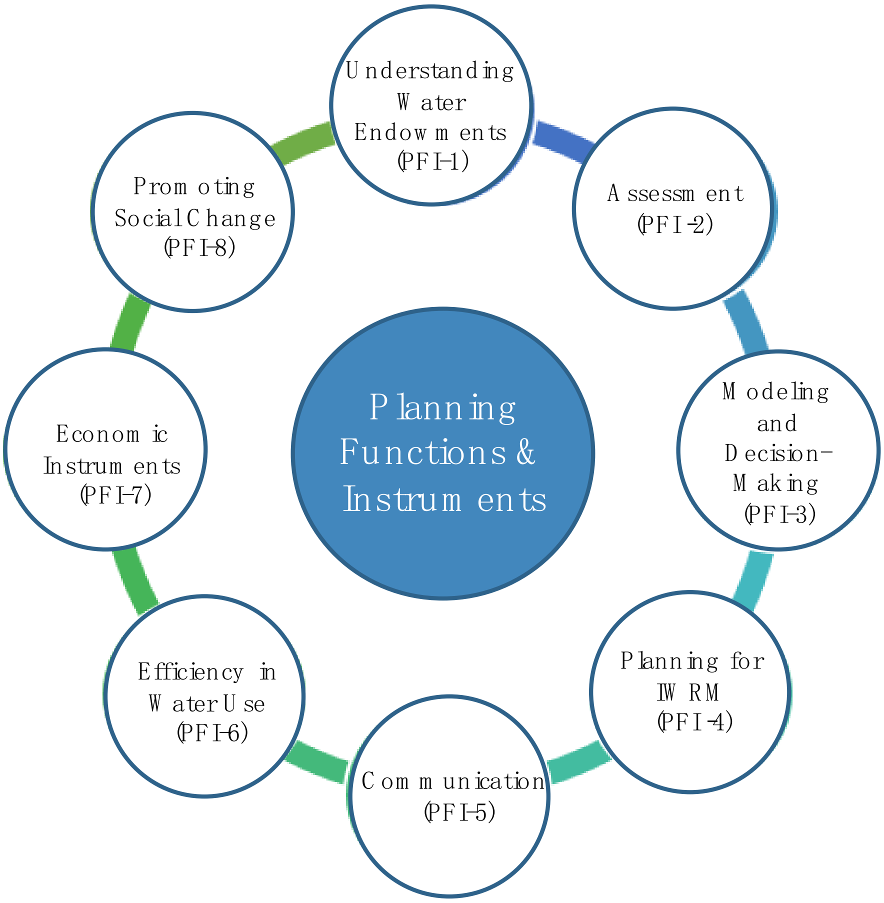
Appendix A – 8 types of Planning Functions & Instruments for Strategic Planning of Integrated Water Resource Management



Understanding Water Endowments (PFI-1) – Helps to understand water as a physical resource. To that end, it considers the analysis of Demand and Supply (PFI-1.01), the collection of data on the hydrological cycle (PFI-1.02), the valuation of the resource itself, as well as the monitoring of water quality and the evaluation of water policies (PFI-1.03).

Assessment (PFI-2) – Helps to understand the connections between water resources and their users as well as to calculate the impacts of uncertain events or policy measures on the resource and its users. The aspects considered are risk (PFI-2.01) and vulnerability (PFI-2.02), social structures and effects (PFI-2.03), ecosystems (PFI-2.04), environment (PFI-2.05), and economics (PFI-2.06).

Modelling and Decision-Making (PFI-3) – Visualizes the information that has been gathered and helps to make decisions based on that information according to jointly established criteria with stakeholders. For that purpose, it includes further information on GIS (PFI-3.01), Stakeholder Analysis (PFI-3.02), Shared Vision Planning (PFI-3.03), and Decision Support Systems (PFI-3.04).

Planning for IWRM (PFI-4) – On the basis of knowledge gained through assessments and modelling processes, plans can be made that integrate environmental, social and economic aspects of water management on different scales: on the national level (PFI-4.01), river basin level (PFI-4.02), with regards to ground water (PFI-4.03), or coastal areas (PFI-4.04). These plans can also address the specific requirements of particular settings or situations, such as urban water management (PFI-4.05), disaster risk management (PFI-4.06), or national adaptation plans (PFI-4.07).

Communication (PFI-5) –Water management does not take place in a vacuum. It involves a variety of stakeholders and relies heavily on sharing knowledge in order to design effective plans and foster participation.

For that reason, an overview on Communication Tools (PFI-5.01) is given and measures to prevent and deal with conflict are explained, such as Consensus Building (PFI-5.02) and Conflict Management (PFI-5.03).

Efficiency in Water Management (PFI-6) – Refers to measures that improve the management of demand and supply by enhancing water Demand Efficiency (PFI-6.01) and Supply Efficiency (PFI-6.02). Another way to reach that goal is to Recycle and Reuse (PFI-6.03).

Economic Instruments (PFI-7) – There are different ways to ensure behaviour that is beneficial to the protection of water quality and quantity. Those that are economic in nature are considered here – Water Pricing (PFI-7.01) and Water Markets (PFI-7.02), for example, but also Tradable Pollution Permits (PFI-7.03) and Pollution Charges (PFI-7.04), Subsidies (PFI-7.05), and Payments for Environmental Services (PFI-7.06) that penalize certain kinds of behaviour and reward others.

Promoting Social Change (PFI-8) – Social attitudes also play a big role in determining behaviour. In order to ensure behaviour that promotes water security, social change might be necessary. A change in attitudes can be fostered through the integration of water management into Youth Education (PFI-8.01), and through Raising Public Awareness (PFI-8.02). The concept of the Water Footprint (PFI-8.03) can be helpful to explain the relationship between water and agricultural and industry, and Virtual water (PFI-8.04) to learn about how much water is used in the industrial production of goods.

Appendix B – Interview Questions used with Interviewees

Warm up / background

> *[Goal: Determine where the interviewee's focus is. Prioritize subsequent sections accordingly]*

- Tell me a little bit about yourself, how did you get into the water business?

Role of Water Data in Strategic Planning

- Across the myriad of data available today, what insights are important to your organization? Are you able to gather these insights today? If so, how? If not, why not?
- What are the key performance indicators you're tracking today? What are the metrics you use? How do you track this today?
  - How do you or your team interact with data modelling or utilize the insights from modelling, if any?
- What business functionalities in your organization rely on utilizing water data or insights generated from data?

Planning Functions & Instruments used in Strategic Planning

- Are you familiar with the water indicators supplied by service providers? If so, how does your organization use that information today for strategic planning?
- Are you familiar with water mass balance? If so, how is that information accessed or analyzed? Please describe to the best extent you know.
- What other methodologies or frameworks do you use?

Perception of water data's overall utility value in IWM approaches to strategic planning

- What is your involvement with integrated water management? What is your perception of its purpose?
- What are your team's top pain points with the water data available to you today? What technologies are you exploring to solve them?
- If these required insights or data are made readily available to you & your organization, what is your organization's willingness to pay?

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Wrap-up

- As a wrap up, do you have any suggestions or see any gaps in the water data space that you'd like to point out?
- Thanks for the time: as a token of our appreciation, would it be valuable for us to get X based on our research?

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