Urban CALculator Model (UrbanCALM) - Consistent and Efficient Framework for Urban Water Balance Analysis and Reporting: 2. Verification and Application

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Abstract

The verification of UrbanCALM was carried out based on a case study of its application to the Melbourne Region in Victoria, Australia. This region is served by a complex water system formed by integrated operations of multiple urban water utilities. Results demonstrated that UrbanCALM provides a user-friendly tool which enabled stepwise and systematic representation and evaluation of the Melbourne regional water system in 2012-2013. The study presented useful features in UrbanCALM such as the multiple checks provided to identify gaps and anomalies in usage of urban water data, which enable consistent and accurate interpretation of flows and urban water balance evaluations. The transferability and capabilities of the UrbanCALM framework were tested via its application to six major Australian population centres/cities reported on in the National Water Account. These urban centres / regions are served by water systems with varying level of complexity in terms of: area served; water intake, transfers and supplies for use; and wastewater collection, treatment, discharge and recycling. The study demonstrated that UrbanCALM provides 'one consistent framework' flexible and applicable in a consistent manner to 'six major urban regions. In conclusion, UrbanCALM facilitates consistent and efficient water balance evaluations and strengthens the ability of agencies such as the Bureau of Meteorology to produce high quality water information reporting products. The framework is applicable to any urban water system nationally and internationally. It enables insights, provides transparency and better understanding of the urban system, and thus it can be recognised as a useful tool for urban water managers to address the needs of growing urban centres and populations. This study reveals the strong potential for its broad application across all Australian urban centres as well as internationally.

Keywords: UrbanCALM, Urban Calculator Model, system analysis, urban water balance framework, urban water system

1. INTRODUCTION

This paper presents the verification and application of the Urban CALculator Model (UrbanCALM) developed to provide a consistent and efficient urban water balance evaluation framework (described by Jayatilaka and Elmahdi, 2015). Initially, the verification of UrbanCALM is presented and discussed in section 2 based on its application to assess the complex water system of the Melbourne region in Victoria, which encompasses the second largest metropolitan area in Australia. This case study clarified the process involved in applying the UrbanCALM concept to a given region.

Section 3 of this paper presents and discusses the application of UrbanCALM framework to other urban centers in Australia to test its ability in representing and analyzing diverse water systems. All major Australian urban centers / regions reported on in the National Water Account (BoM, 2014) were considered for this application. These regions vary in terms of area and population, and represent water systems with varying level of complexity. Also in section 3, the transferability of the UrbanCALM framework and its capability to facilitate consistent and efficient water balance analysis and reporting at the national scale is discussed.

2. VERIFICATION OF THE MODEL - CASE STUDY

This case study focused on the Melbourne region, located in the southeast of mainland Australia (Figure 1), which extends over four river catchments: Yarra, Bunyip, Maribyrnong and Werribee (Table 1). It is a major urban region which represents a complex urban water systems formed by the integrated operations of multiple urban water utilities. The aim of this study was to test the UrbanCALM concept that was presented in paper one (Jayatilaka and Elmahdi, 2015) by applying it to analyze the water system of the Melbourne region in 2012-2013. The first step in this process was untangling of the regional water system by identifying the water systems managed by each water authority/utility (bulk and retail) and associated conceptual flow components (urban water pathways). The second steps was capture of data (metered or estimated) from the relevant water authorities to quantify the flow components of each water system. Third step was aimed at evaluating the water balance of each system by a detailed analysis of its subsystems. This step was completed for the urban water systems managed by all utilities. The fourth step was the derivation of the integrated regional water system from the utility based systems (completed in step three). The last step allowed to examine the consistent reporting capabilities of UrbanCALM, e.g. ability to generate automated output via templates that are appropriate to provide input for the Water Information (WI) products such as the National Water Account (NWA) Australian Water Resources Assessment report, and city based urban water reporting.

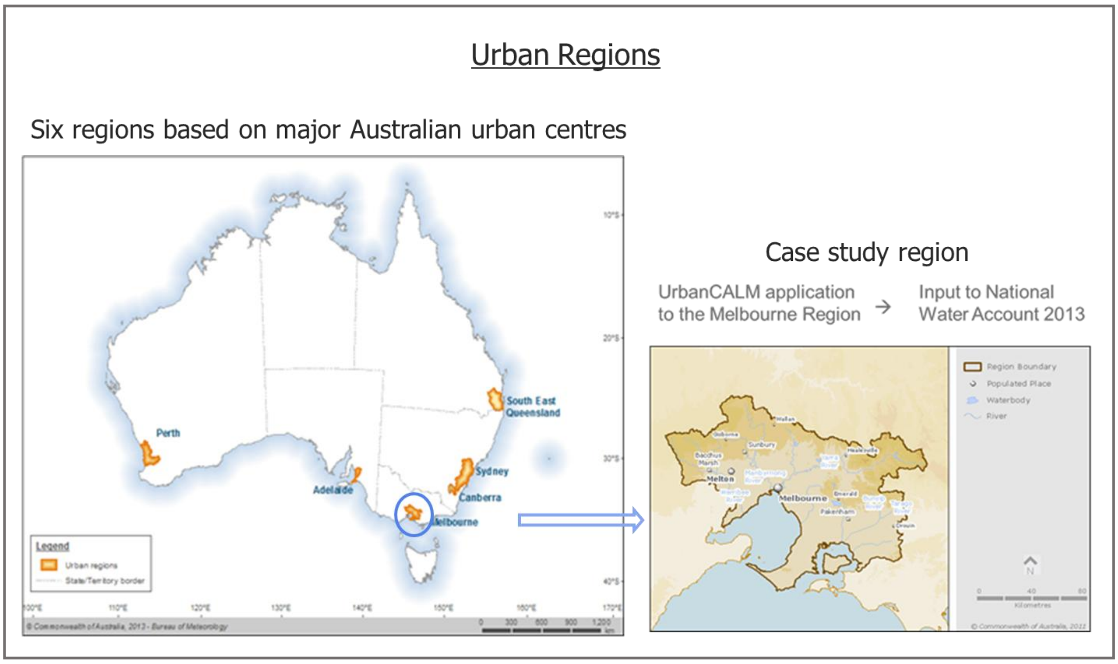


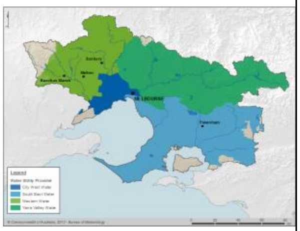
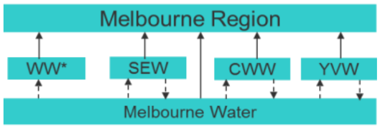
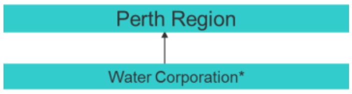
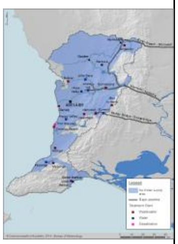
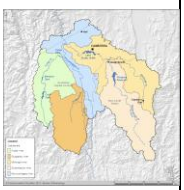
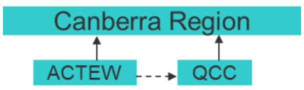
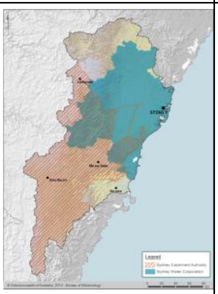
Figure 1: Urban regions considered for the verification and application of UrbanCALM

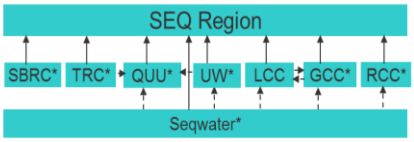
2.1. Case Study - Results and Discussion

The first step of the model application started by analyzing conceptual flow pathways which represent transfers between water authorities/utilities that provide water services in the study area. This analysis continued identifying water flow paths resulting from the intake of water from different sources, water supply for use, wastewater collection and treatment, disposal and recycling. Figure 2 summarizes the pathways identified in the Melbourne region (representing the bulk water authority - Melbourne Water, and the retail water authorities - Yarra Valley Water, City West Water, South East Water and Western Water). This step enabled derivation of the 'regional linkage', which assists with compiling the regional water system from the water systems managed by each water authority (i.e. as utility scale systems).

In this study, UrbanCALM provided a guiding tool from data capture (on flow components of the identified water systems), through interpretation and analysis to the output derivation. The 'calculator' module facilitated stepwise and systematic evaluation of water balances within each subsystem at the utility scale water systems: (1) water supply system, (2) wastewater system, and (3) recycled water system. It clarified the steps involved and the multiple checks in the process that enabled detection of any data anomalies, missing or incomplete flow components. These features made UrbanCALM a user friendly tool that helps to alleviate misinterpretation of data, and enabled it to serve as platform for communication with stakeholders to obtain missing flow components (where the required information was available). This process facilitated consistent and accurate water balance evaluations at the utility scale systems. The integrated 'regional' urban water system was derived by assembling the evaluated utility based systems in a manner that depicts the regional linkage as shown in Figure 2.

Table 1: Six regions based on major Australian urban centres

Region	**Urban Water Authorities**
Melbourne  **Area:** 11,723 km² **Population:** 4.1 million approximately; **Water Sources^** **Primary:** Surface water; **Secondary:** Groundwater **Other:** Recycled water; Desalinated water - not in use yet	 Bulk water provided by: Melbourne Water Corporation (Melbourne Water) Retail water authorities: City West Water (CWW); South East Water (SEW);Yarra Valley Water (YVW); and Regional water authority: Western Water (WW); **Small part of the service area outside the region; Part of the surface water intake from storages managed by Southern Rural Water*
Perth  **Area:** 21,156 km² **Population:** 1.9 million **Water Sources^** **Primary:** Groundwater Surface water and Desalinated water **Other:** Recycled water	 Water authority: Water Corporation **Service area extends across the NWA region boundary*
Adelaide  **Area:** 5,350 km² **Population:** Approximately 1.3 million **Water Sources^** **Primary:** Surface water **Other:** Desalinated water, Recycled water	 Water authority: SA Water **Service area extends across the NWA region boundary* ***Note**: **Mainly dependent on River Murray** water transferred (imported) to the region via pipelines*
Canberra  Area: 4,202 km² Population: 421,700 Water Sources^ Primary: Surface water **Other:** Recycled water	 Urban water authorities: ACTEW Water (ACTEW) and Queanbeyan City Council (QCC)
Sydney  **Area:** 30,800 km2 **Population:** 4.71 million **Water Sources^** Primary: Surface water **Other:** Desalinated water, Recycled water	 Water authorities / Councils: Sydney Water Corporation (SWC); Wingecarribee Shire Council (WSC); Shoalhaven City Council (SCC); Goulburn Mulwaree Council (GMC); Lithgow City Council (LCC) *Sydney Catchment Authority manages catchments, reservoirs and other infrastructure and provides raw water to Sydney Water and Shoalhaven, Wingecarribee and Goulburn Mulwaree councils.* **Service area extends across the NWA region boundary*

Region	**Urban Water Authorities**
South East Queensland (SEQ)  **Area:** 21,331 km² **Population:** 3,178,030 **Water Sources^** **Primary:** Surface water **Other:** Desalinated water, Recycled water	 Bulk water provided by: Seqwater Retail water authorities / Councils: Queensland Urban Utilities (QUU); Unitywater (UW); Logan City Council (LCC); Gold Coast City Council (GCC); Redland City Council; Toowoomba Regional Council;South Burnett Regional Council; **Service area extends across the NWA region boundary*

^**Water sources** included in the table are limited to those taken in to the Urban Water Systems for the supplies managed by the Water Authorities shown; Stormwater intake for use and water taken for use by individuals or other organisations are not included; Area and population (Source: http://www.bom.gov.au/water/nwa/)

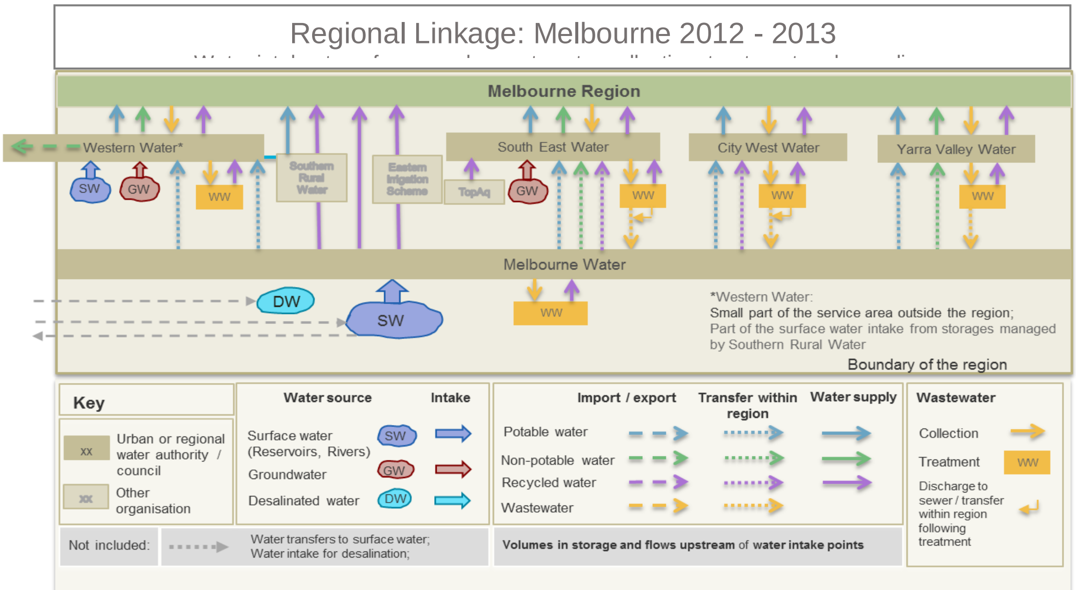


Figure 2: Linkage for deriving Melbourne regional water system

UrbanCALM enabled automated output clarifying water balance and flow components of each subsystem. The outputs can be displayed via a common template at both utility and region scales. Figure 3 presents the summary of the regional urban water system derived in this case study; Table 2 includes a summary of the water balance in each subsystem of the regional water system, and Table 3 includes detailed water balance of one of the subsystems (i.e. water supply system) at the region scale as an example. The information on each subsystem (inflows, outflows and system error) indicates the extent to which the water balance has been achieved based on the available information, and this helps to view results with confidence (e.g. as in this case the error being less than 2% of the system inflow). In particular, at the water utility scale, such detailed analysis helps to identify the subsystems which require more information to confirm or quantify flows for improving the water balance. The 'link' module in UrbanCALM enabled derivation of output as required by WI products. For example, in this case the automated output generated based on the balanced regional water systems via the appropriate templates provided input for the National Water Account (NWA) 2013 (as discussed in Section 3.2, as part of the application of the model to six major Australian urban centers).

In addition to the water utility and region scale systems discussed, water systems at the city scale can be derived. This can be achieved in the case of Melbourne by linking the checked and balanced water systems that are managed by the bulk water authority (Melbourne Water) and the retail water authorities Yarra Valley Water, City West Water and South East Water. As such, UrbanCALM can facilitate a consistent water balance evaluations and reporting at multi-scales (e.g. water utility, city and region scales).

3. APPLICATION OF THE MODEL FOR OTHER CITIES

The application of UrbanCALM framework was tested based on its ability to represent the water systems of major Australian urban centers. In addition to the Melbourne region considered for the case study, the framework was applied to analyze the regional urban water systems of: Sydney, South East Queensland (SEQ), Canberra, Adelaide and Perth (Figure 1 & Table 1) in 2012-2013. These urban regions differ in terms of area, population and climate, and represent water systems with varying complexity with respect to: water sources, intake, transfers and supplies for use; wastewater collection, treatment and disposal; and water recycling for use. In each region, UrbanCALM was applied according to the steps discussed in the case study (Section 2), starting from untangling of the regional system, through data capture, analysis, and generation of outputs for provision of input to the NWA 2013 (BoM, 2014). This application tested the transferability of the UrbanCALM framework and its capability to facilitate consistent and efficient water balance analysis and reporting at the national scale and multiple scale

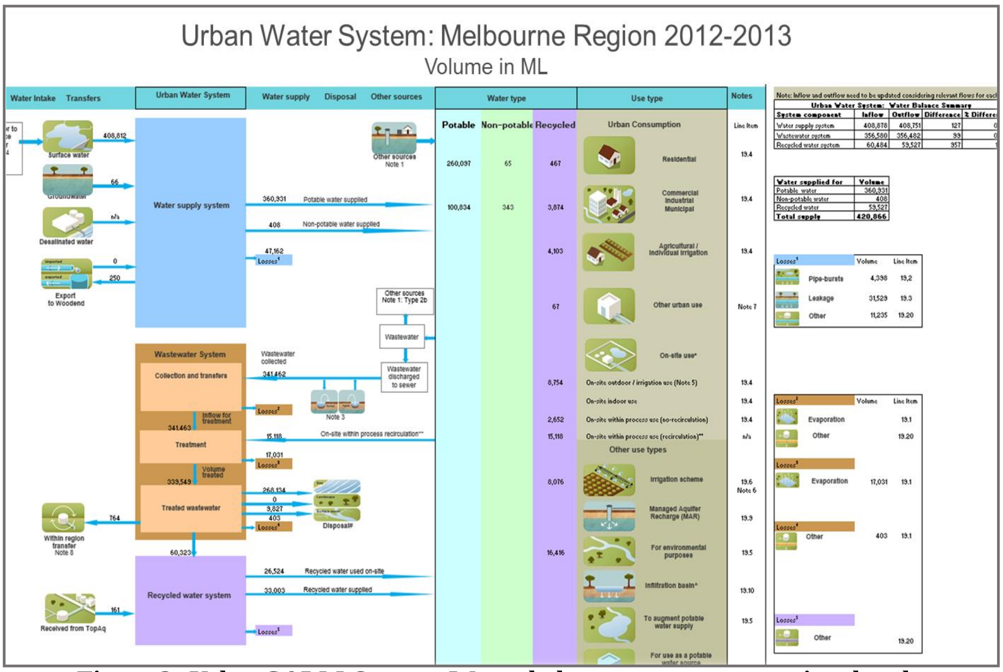


Figure 3: UrbanCALM Output: Water balance summary at regional scale

Table 2: Water balance summary of the six regional urban water systems

Region	Urban Water System: Water Balance Summary (2012-2013)				
	Subsystem	Inflow	Outflow	Difference*	Error
Melbourne	Water supply system	408,878	408,751	127	0.03%
	Wastewater system	356,580	356,482	98	0.03%
	Recycled water system	60,484	59,527	957	1.58%
Perth	Water supply system	327,184	327,315	-131	-0.04%
	Wastewater system[1]	136,356	136,358	-2	0.00%
	Recycled water system[2]	10,190	10,190	0	0.00%
Adelaide	Water supply system	162,173	160,033	2,140	1.32%
	Wastewater system	93,455	92,027	1,428	1.53%
	Recycled water system	28,975	28,975	0	0.00%
Canberra	Water supply system	47,904	47,893	11	0.02%
	Wastewater system	40,508	40,508	0	0.00%
	Recycled water system	4,995	4,995	0	0.00%
Sydney	Water supply system[3]	539,875	537,594	2,281	0.42%
	Wastewater system	521,521	521,384	137	0.03%
	Recycled water system	51,616	51,615	1	0.00%
SEQ	Water supply system	251,897	252,658	-761	-0.30%
	Wastewater system	249,406	248,307	1,099	0.44%
	Recycled water system	23,241	23,464	-223	-0.96%
	Advanced water treatmen	2,914	2,853	61	2.09%

* Based on rounded volumes used to provide input to NWA 2013; Volumes following further revision of data:
[1]Inflow = 136,392 ML, Outflow = 136,394 ML; [2]Inflow 10,422 ML, Outflow = 10,422 ML; [3]Inflow 543,311 ML

Table 3: Consistent water balance analysis of the water supply system across regions

Water Supply System: Inflow and Outflow Components (Volume in ML)

Component	Melbourne	Perth*	Adelaide	Canberra	Sydney*	SEQ
Inflow						
Volume taken from surface water	**408,812**	**91,792**	**118,922**	**47,904**	**539,279**	**224,420**
Volume taken from groundwater	**66**	**139,622**	**n/a**	**n/a**	**0**	**158**
Volume taken from desalination	n/a	**95,770**	**36,472**	n/a	**0**	**2,805**
Potable water imported	n/a	n/a	6,779	n/a	596	24,514
Non-potable water imported	n/a	n/a	n/a	n/a	**0**	n/a
Total volume imported	**0**	**0**	**6,779**	**0**	**596**	**24,514**
Potable water received / transferred in	n/a	n/a	n/a	n/a	**0**	n/a
Non-potable water received / transferred in	n/a	n/a	n/a	n/a	**0**	n/a
Total volume received / transferred in	**0**	**0**	**0**	**0**	**0**	**0**
Total inflow	**408,878**	**327,184**	**162,173**	**47,904**	**539,875**	**251,897**
Outflow						
Potable water discharge to surface water	n/a	**70,877**	**2,423**	**66**	**0**	n/a
Non-potable water discharge to surface water	n/a	n/a	n/a	n/a	**0**	n/a
Potable water exported	**0**	1,259	4,053	n/a	**4,468**	n/a
Non-potable water exported	250	n/a	n/a	n/a	0	n/a
Total volume exported	**250**	**1,259**	**4,053**	**0**	**4,468**	**0**
Potable water delivered / transferred out	n/a	n/a	n/a	n/a	**0**	n/a
Non-potable water delivered / transferred out	n/a	n/a	n/a	n/a	**0**	n/a
Total volume delivered / transferred out	**0**	**0**	**0**	**0**	**0**	**0**
Potable water supplied for use	**360,931**	**226,189**	**137,028**	**43,754**	**469,145**	**219,137**
Non-revenue potable water - pipe bursts	4,398	0	0	0	0	0
Non-revenue potable water - leakage^	31,529	20,583	16,529	2,803	44,899	27,613
Non-revenue potable water - remaining	11,105	8,407	0	1,270	15,686	5,653
Total non-revenue potable water (losses)	**47,032**	**28,990**	**16,529**	**4,073**	**60,585**	**33,266**
Non-potable water supplied for use	**408**	**0**	**0**	**0**	**3,396**	**255**
Total non-revenue non-potable water (losses)	**130**	n/a	n/a	**0**	**0**	**0**
Other losses	n/a	n/a	n/a	n/a	n/a	n/a
Total outflow	**408,751**	**327,315**	**160,033**	**47,893**	**537,594**	**252,658**
Inflow - Outflow	127	-131	2,140	11	2,281	-761
Error	0.03%	-0.04%	1.32%	0.02%	0.42%	-0.30%

*Volumes prior used to provide input to NWA 2013 (prior to revisions afterwards); ^Where volume of pipe bursts is not provided separately that'd be part of the volume of leakage shown.

3.1. Results and Discussion

The urban systems considered in this study are managed by a single water authority (Perth, Adelaide), and multi-utilities (SEQ, Sydney, Melbourne and Canberra) as shown in Table 1. There were differences in the water balance components that formed these urban systems. Despite this diversity, the process described in the application of UrbanCALM to the Melbourne region (detailed in Section 2) was consistently applied in each region, demonstrating its flexibility and capabilities.

The urban water pathways analysis in each region identified the number of utility scale water systems and the associated water intake, imports, exports, transfers occur as part of provision of water supply, wastewater and recycled water services. The results enabled derivation of the 'regional linkage' as summarized in Figure 4. In multi-utility regions, the regional linkage provided the basis for linking the utility based systems to derive the regional water system. UrbanSAT (input module of UrbanCALM) served as the common template to capture data on each water system identified. It included the capacity to accommodate data on different types flows associated with these diverse systems, and streamlined the data capture, helping to maintain consistency across regions. The calculator module of UrbanCALM guided the water balance evaluations in each subsystem of the urban water systems (i.e. water supply system, wastewater system, and recycled water system).

The use of the same set of steps and checks provided by the calculator module in the analysis of subsystems ensured the consistency and accuracy in interpreting the flow components and in achieving the water balance. The water system of each region was compiled by linking the checked and balanced utility based systems according to the relevant regional linkage (Figure 4). This process ensured that the consistency achieved at the subsystem level at the water utility scale is carried on to the region scale, thus providing a common basis for the water balances across regions, and enabling the outputs derived on the regional systems to be meaningful.

The framework generated outputs for incorporation in the WI products based on the checked and balanced water systems in each region providing a defendable and verifiable basis for the derivations.

For example, schematics of each regional water system in 2012-2013 were generated along with the relevant water balance summary, based on the template shown by the example in Figure 3. A summary of the water balance achieved in each regional system is given in Table 2, which shows that the system error remained low (< 2.1%) providing confidence in the output derived based on the UrbanCALM framework. The detailed water balance consistently carried out in each region is presented in Table 3 using the water supply system as an example. The water balance evaluated through the UrbanCALM process can be used to derive output providing improved transparency of water flow through urban water systems. As appropriate for each region, the 'link' module in UrbanCALM converted the balanced and checked water balance components to the urban 'line item volumes' reported in the NWA 2013 (BoM, 2014). The output generated included schematics providing transparency of the flow through each subsystems at the regional scale, for example as illustrated by the schematics included in the following NWA line items reporting on the Melbourne region:
Line item 19.4 (BoM, 2014):
http://www.bom.gov.au/water/nwa/2013/melbourne/statement/notes_s19_4.shtml
Line item 11.4 (BoM, 2014):
http://www.bom.gov.au/water/nwa/2013/melbourne/statement/notes_s11_4.shtml.

3.2. Six regions and one framework

The application to major Australian cities as discussed above, demonstrated that UrbanCALM is transferable to systems with varying level of complexity. The results show that it provides 'one framework' that is applicable for 'six regions' for representing, analyzing and summarizing urban water balance in a consistent manner: at regional scale in Adelaide and Perth (each served by a single water authority); and at water utility and regional scales (through appropriate aggregation of the utility based water systems) in Melbourne, Sydney, Canberra regions, and in South East Queensland (served by a complex, multi-utility water system). This study demonstrates that the common urban water balance components as well as system specific flows were accommodated within the consistent water balance framework. Examples of the system specific flow components include: flow back to storage from the water supply system (Canberra, Perth), recycled water on-site with-in-process recirculation use (Melbourne, Sydney, Canberra, Adelaide and SEQ); treated wastewater discharge to sewer for further treatment (Canberra); recycled water advanced treatment (SEQ); multiple imports for water supplies (Adelaide); and water grid based supply systems (Perth, SEQ). The framework can represent intake of different water sources (such as traditionally used and system generated) and supplies to common urban uses as well as other more specific uses in urban regions. For example, the framework represented supply of recycled water to use in Managed Aquifer Recharge (MAR) schemes (Perth, Adelaide) and infiltration basins to augment groundwater (Perth), and for environmental purposes (Melbourne). Any volumes sourced from MAR schemes are also accounted for as that would form part of the intake from groundwater. The framework has the capacity to represent recycled water supplies to other uses such as discharge to surface water to augment water supply, and direct use of the advanced treated recycled water.

This study found that the UrbanCALM framework is applicable to diverse water systems with different levels of complexity and provides a consistent and efficient framework for data capture, water balancing and reporting at multiple scales (utility, city, regional or national). The framework also serves as a valuable tool to enhance existing knowledge and improve skills and capacity of teams, and facilitates communication and co-operation between the stakeholders. It can play an important role in delivering high quality water information products for providing increased access to 'accurate' and 'timely' information' on urban water systems, which is a key requirement that can assist urban water managers in addressing the challenges faced. Consistently and accurately evaluated water balances can provide valuable insights within a region, and across regions at the national scale. Figure 5 provides an example based on selected water balance components across the major Australian urban regions considered. Such insights could assist in the development of water management and conservation strategies. Consistent evaluations over several years allow identification of trends and enhance the understanding of the water systems much needed in addressing the challenges posed by growing populations and urban sprawl. The UrbanCALM framework can be applied to any urban water system nationally or internationally where there is sufficient data to quantify the relevant flows.

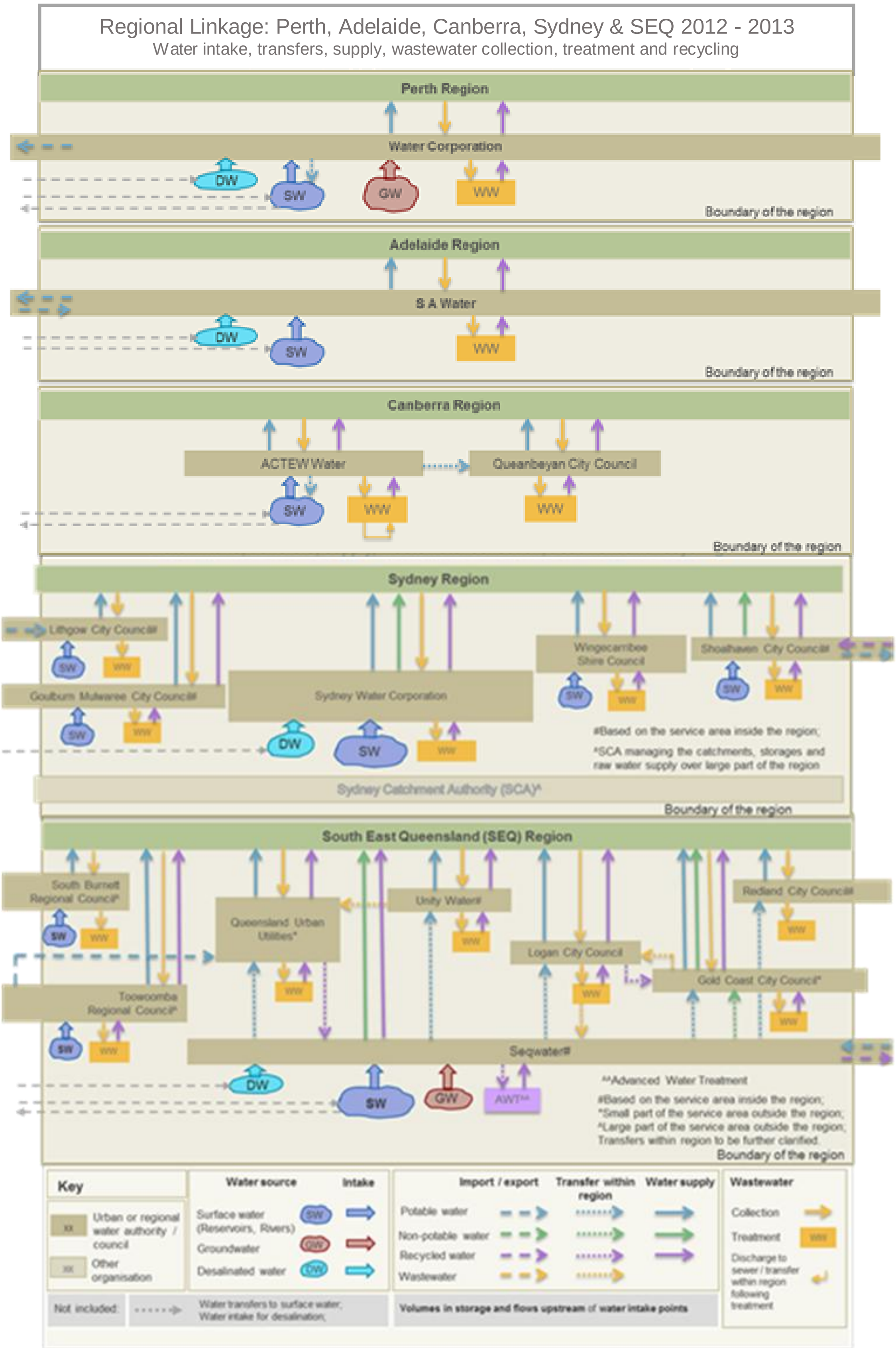


Figure 4: Linkage for deriving regional urban water systems: Perth, Adelaide, Canberra, Sydney and SEQ

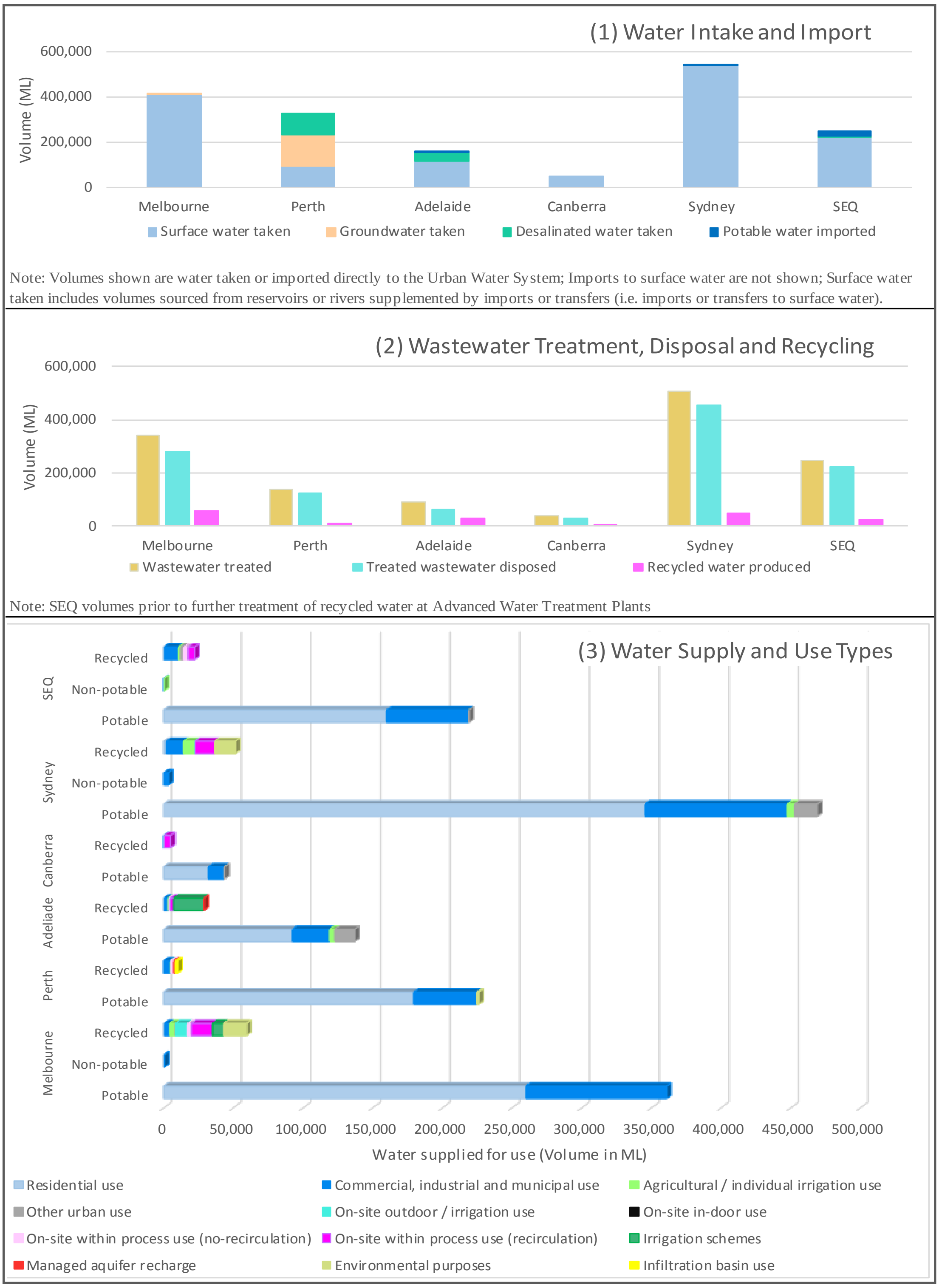


Figure 5: Selected water balance components of urban systems in six region in 2012 – 2013

4. SUMMARY AND CONCLUSIONS

Urban water systems have become increasingly complex with incorporation of various flows as part of providing safe and reliable water services for growing populations and urban sprawl. As pointed out in the first paper, it is a challenge to identify a generic urban water balance framework that is transferrable and nationally applicable for representing, analyzing and reporting on urban water systems consistently. This paper presented the verification and application of the Urban CALculator Model

(UrbanCALM) that provides a consistent and efficient framework for urban water balancing and reporting on both simple and complex systems. The results presented demonstrated its applicability and transferability at different spatial scales and across regions.

The case study (model verification) on the Melbourne region clarified the process of application of the UrbanCALM concept to a given region, and highlighted several useful aspects of the model. The study found that UrbanCALM provided a user-friendly tool and enabled stepwise and systematic untangling, representation and evaluation of the complex urban water system of the Melbourne region in 2012-2013. The study exposed useful features in UrbanCALM that facilitate consistent interpretation of flows and water balance evaluations in each 'subsystem' of the urban water system: water supply system, wastewater system, and recycled water system. These include the steps and multiple checks that guide the analysis to achieve water balances in a consistent and accurate manner at the utility scale. The method adopted in UrbanCALM for linking the checked and balanced utility scale systems to derive the regional (or city) scale systems ensured consistency and accuracy is maintained at multiple scales is (e.g. utility, city or regional). The automated outputs from the model clarified the balance achieved and quantified flows associated with each subsystem at the utility as well at the regional scale.

This paper also presented the results from the application of the UrbanCALM framework to evaluate five other water systems of major urban regions in Australia in 2012-2013 (Sydney, South East Queensland, Canberra, Adelaide and Perth), in addition to the Melbourne region considered in the case study. The application showed that UrbanCALM provides 'one framework' flexible and applicable to 'six major urban regions' for analyzing and summarizing urban water balance in a consistent manner. The results highlighted the flexibility of the framework to accommodate diverse urban water systems with varying complexity and system specific features, and provided evidence of its application at the national scale. Utilizing appropriate linkages, UrbanCALM converted the checked and balanced urban water balance components to the items as required by WI products. It enabled automated flow of information to templates in formats that can be appropriate for incorporation in the Bureau's WI products, providing greater transparency on the water balances and flow though the systems.

In conclusion, UrbanCALM is able to facilitate consistent and efficient water balance evaluations, strengthening reporting agency's capacity to produce high quality water information products. It serves as a platform to obtain defendable and repeatable results by deriving output based on the checked and balanced urban water systems. UrbanCALM presents a valuable tool to facilitate communication and enhance co-operation among relevant stakeholders. The framework is applicable to any urban water system nationally and internationally. It enables insights providing improved transparency and understanding on urban systems, and thus can be a useful tool to urban water managers in addressing the needs of growing populations and urban sprawl. This study reveals the strong potential for its application within the broader water industry realm at a national and international scale.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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