Chapter 1

Introduction

> "Thus, a new approach and novel technical solutions for water management and treatment in cities must be developed and implemented. The new approach must be based on resource conservation principle as an opposite to treatment at end of pipe. Efforts must be taken to introduce small-scale, low cost technology that is based on local traditions, decentralised and ecologically sound." Janus Niemczynowicz [1996].

1.1 The Growth of Water Monopolies and the Marginalisation of the Use of Rainwater Tanks

The site for Australia's first settlement named Sydney was chosen in 1788 at the location of the finest freshwater spring available [Roseby, 1918]. This spring known as the Tank Stream was the original and highly variable source of water for Sydney. Indeed the settlement was regularly subject to droughts, floods and water shortages.

The settlement grew rapidly forcing citizens to supplement water supply from the Tank Stream with water from wells, underground tanks and other springs. Australia proved to be a dry country with highly variable rainfall. Water became a valuable commodity and was sold from public wells to citizens at a price of 1d per bucket and 6d per cask in the 1840s.

During the nineteenth and twentieth centuries Australia was subject to rapid urban population growth with an economic focus on industry and commerce resulting in dramatic increases in the demand for water [IEAust., 1999]. Water scarcity was common in urban areas. Dams were constructed on rivers to provide reliable water supply to cities. Water from dams is transported via pipes across large distances to meet urban water demand.

The development of water supply in the Lower Hunter region of New South Wales is a well documented and typical example. In the nineteenth century the principal domestic water source in the Lower Hunter region was rainwater collected from roofs and stored in tanks that were either built on the ground or buried underground. It was often suggested that coal dust and disease entered domestic supplies via roofs. However, rainwater stored above ground caused very few health problems [Lloyd et al., 1992].

Unfortunately, underground rainwater tanks posed a very different health risk due to their permeability to stormwater and sewage inflows. Many underground rainwater tanks were poorly constructed and situated adjacent to cesspits in household yards. Sewage readily percolated from the cesspits into the underground rainwater tanks and groundwater flowed from the cemeteries on higher ground into the underground rainwater tanks. In the 1890s outbreaks of typhoid were common [Lloyd et al., 1992].

In times of drought, the domestic rainwater tank would empty and sewage remained in the streets and household yards because there was not enough rain to wash it away. At these times citizens would call for a reliable water supply and sewage disposal system [Armstrong, 1967].

The first permanent water supply in the Lower Hunter region was provided in the 1880s. Unfortunately the supply was often of poor quality and unsuitable for basic household uses. Although citizens had called for a reliable water supply they preferred to rely on their household rainwater tanks whilst rainfall was plentiful and to source water from standpipes provided in public places when the rainwater tanks were empty.

The destruction of two houses in Maitland by fire led to more calls for a reliable water supply to enable the community to fight fires. The Walka water supply scheme was built and connected to East Maitland, Newcastle and Morpeth in the 1880s.

Citizens refused to connect to the permanent water supplies and, more importantly, pay for water from those supplies. The Walka water supply cost £350,000 to construct and £18,000 was needed every year to pay interest and operating expenses. In 1892 the local councils that administered the new permanent water supplies were in serious debt. The government did not have the power to force people to connect to mains water or to charge citizens whose properties were not connected.

The Hunter District Water Supply and Sewerage Act became effective in 1892 requiring all properties to pay for the mains water supply even if they did not use it to ensure that government debt be repaid [Armstrong, 1967; and Lloyd et al., 1992]. The reluctance of the community to part with their rainwater tanks had threatened the economic viability of the emerging centralised water supply paradigm. The legislated mandatory fixed charges ensured that citizens used mains water in preference to household rainwater tanks.

The British Royal Commission into Sewerage Disposal (1898 – 1915) was established to find acceptable solutions for the disposal and treatment of the sewage that often remained in streets and household yards [Beder, 1993]. The Royal Commission [1908] recommended water carriage of sewage via pipes from households to waterways as an acceptable solution. A significant impact on the use of rainwater tanks was the commission's recommendation that wastewater (including roof water) be discharged directly to a street disposal system.

The currently accepted solution for sewage disposal did not come from considerations based on technical excellence or a publicly agreed solution [Beder, 1997, pp.133-139]. Rather it evolved from the practices of a small group of professionals that desired control of the industry. Indeed the sewage disposal paradigm has been subject to constant failure since its inception creating serious health and environmental concerns. In spite of this, the sewage disposal paradigm has remained relatively unchanged, limited to a narrow range of accepted technologies by a controlling profession that sets design rules and performance standards.

By requiring engineers to design sewage disposal systems that conform to accepted rules (which are the limited set of acceptable solutions set by the professionals that control the sewage disposal paradigm) a sustainable solution for urban development may never be found. Current practice is to set performance standards that can be (easily) achieved by solutions within the narrow paradigm rather than performance standards that are based on desired environmental outcomes [Beder, 1997, pp.133-139]. Consequently, there is no incentive to find better solutions that will reduce environmental impact. It is suggested that the water supply and stormwater disposal paradigms have evolved in a similar fashion.

The practice of discharging roof water (and stormwater) directly to the street disposal system has been copied from the sewage disposal paradigm and adopted as acceptable practice in the stormwater drainage paradigm. Stormwater drainage standards such as the New South Wales Code of Practice Plumbing and Drainage [Committee on Uniformity of

Plumbing and Drainage Regulations in NSW, 1999] and Australian Rainfall and Runoff [IEAust, 1987] perpetuate this practice by recommending discharge to stormwater drains, combined sewers or stormwater channels.

Stormwater runoff from urban allotments is collected in street gutters and pits, and conveyed to waterways via pipes [IEAust, 1987]. Current stormwater management practice is to design a pipe drainage system in streets with contributing pervious and impervious areas. The hydrological dynamics and mitigation possibilities on urban allotments are largely ignored in the design process. However approximately 75% of impervious surfaces in urban catchments are on allotments. These impervious surfaces are directly connected to the street drainage system resulting in increased peak and total stormwater discharges, downstream local flooding, erosion, sewer surcharges and requiring expensive “big pipes” infrastructure to mitigate nuisance flooding in accordance with current practice.

Prior to the 1990s the use of a rainwater tank was virtually illegal in urban areas. Local government and Water Authorities actively discouraged the use of rainwater tanks via stormwater drainage standards and informing citizens that they were illegal and dangerous. Older citizens in Newcastle remember water authority staff visiting their houses to demand the removal of rainwater tanks telling them that rainwater was dangerous [J. Belshaw, personal communication, 1999].

The prime motivation for a centralised water supply was drought security and the need for a readily available source of water for fire fighting. Public health concerns arose primarily from inadequate sewage disposal systems and, to a lesser extent, poor construction of underground rainwater storages. Indeed public health concerns were the driver for the introduction of centralised sewage disposal systems rather than a permanent water supply.

Interestingly the arguments predominately used to discourage the use of rainwater are public health concerns although limited published studies or data are in existence to justify this position. Indeed about 3 million Australians currently use rainwater from tanks for drinking with no reported epidemics or adverse health effects. The NSW Department of Health point out that they do not prohibit the use of rainwater for drinking or any other purpose [Corbett, 2001].

A recent letter from a water corporation [HWC, 2000] to a local government organization disagrees with the statement in Australian Standards [AS2500.1.2, 1998] that rainwater poses a low hazard insisting that the use of rainwater is a high hazard. This implies that rainwater is more dangerous than grey water and is as hazardous as water from sewage treatment plants, chemical plants, abattoirs, nuclear reactors and pathology laboratories.

Duncan and Wight [1991] explain that use of rainwater is expensive costing up to 8 times the price of mains water and that rainwater has a low "reliability of supply" resulting in the need for very large tanks in Melbourne. They also report poor water quality from rainwater tanks although the references used for water quality could not be traced.

In contrast, Mitchell et al. [1997] found that rainwater tanks used in Melbourne could reduce mains water demand by 40% and stormwater discharges by 56%. Andoh and Declerck [1999] revealed that the use of source control measures would provide stormwater management cost savings of up to 80%. Argue et al. [1998] describes the source control approach as the use of measures to "hold the rain where it falls" a phase that originated in an architecture quarterly in 1974. The source control of stormwater is described as the capture of rainwater where it falls or close to where it falls for flood mitigation, pollution minimisation and rainwater harvesting. Pacey and Cullis [1986] describe rainwater harvesting as an ancient practice. A full definition of the source control concept is provided later in the introduction.

Although centralised water supplies began as economically tenuous ventures they have grown into a wealthy, comfortable and powerful monopolies that operate to maximise profit for shareholders at the expense of environmentally sustainable solutions [Wood, 2000]. The rainwater tank in the modern age does not threaten the viability of water authorities rather it challenges the monopolies and profit margins they maintain.

The water supply, sewage disposal and stormwater management paradigms have narrowed to a limited set of separate centralised solutions that exclude reuse of rainwater as a potential solution. **Have we missed an opportunity to implement a sustainable water supply and stormwater management solution?** A systems approach is needed to devise and understand solutions beyond those permitted by the current paradigms. This thesis will evaluate the use of rainwater tanks in the broader context of source control technology as part of urban water cycle systems.

1.2 Source Control: a Forgotten Opportunity

Urban development and its constructed hydraulic systems cause profound changes to the natural water cycle. The area of impervious surfaces is increased whilst natural watercourses are replaced with hydraulically efficient pipes and channels. The resultant increased volumes and rates of stormwater discharges from traditional urban developments have caused significant degradation of the natural environment [Argue et al., 1998 and 1998a; O'Brien et al., 1992; Wong and Eadie, 2000].

Water demand resulting from urban development is typically met by importing large volumes of water treated to drinking water quality standards, across large distances and at considerable cost, from neighbouring catchments. At the same time similar volumes of stormwater from roofs and allotments are discharged unused from urban developments via expensive stormwater systems [Allen and Argue, 1992; Mitchell et al., 1997]. Less than 1% of urban water consumption is used for drinking. However, all mains water supply is treated to potable quality [Mitchell et al., 1997]. Rainwater collected from domestic roofs could be used to replace a considerable portion of urban water consumption reducing stormwater discharges to downstream environments and the need to harvest and store water for water supply.

Water sensitive urban design (WSUD) is a planning and design concept developed by Whelans et al. [1994] to provide a more responsive approach to the water balance, water quality and water conservation in urban environments. Source control is a stormwater management philosophy that has been largely pioneered in Australia by Argue [1986] involving the capture and management of stormwater and rainwater as close to the point of origin in the catchment as possible. The WSUD concept includes the use of source control measures such as infiltration, landscaping methods and the reuse of rainwater, stormwater and wastewater on urban allotments.

Authors such as Mitchell et al. [1997], Clarke [1990] and Hopkins and Argue [1993] state that management of urban water supply, stormwater and wastewater disposal is highly disjointed and call for a holistic view of the urban water cycle. They suggest the adoption of source control measures to reduce infrastructure costs and environmental impacts.

The traditional urban drainage paradigm involving use of more and bigger capacity pipes to discharge stormwater runoff as quickly as possible results in costly solutions. Andoh and Declerck [1999] show that use of source control measures can result in cost savings of 30% to 80% over traditional stormwater drainage measures. Schilling and Mantoglou [1999] report that in Germany rainwater tanks are subsidised and are used to supply water for toilet flushing and irrigation to avoid the development of new water resources.

Source control is not a new idea. Indeed the use of rainwater tanks and gravel soakage pits to manage stormwater runoff and supply water on urban allotments predates the current stormwater drainage and water supply paradigm. The growth of the pipe transport based paradigms has devalued and subsequently excluded the use of source control measures as acceptable techniques. Source control measures are a forgotten opportunity for urban water cycle management. This thesis evaluates this forgotten opportunity and argues that the reuse of rainwater in the context of WSUD source control methods will provide significant stormwater management, water supply and economic benefits to the community.

1.3 New Ideas and Approaches

This thesis explores the forgotten source control opportunities and presents a number of new ideas for the management of the urban water cycle. A schematic of the urban water cycle is presented in Figure 1.1.

The urban water cycle starts with water extracted from streams and aquifers, stored in reservoirs and then processed to potable quality before delivery through an extensive pipe system to urban allotments. Some of this water is then used to transport wastes through a network of sewers to treatment plants which discharge effluent into receiving waters such as rivers, lakes and oceans. Rainfall falling on the urban allotment contributes to the urban catchment’s stormwater that is collected by an extensive drainage system for disposal into receiving waters.

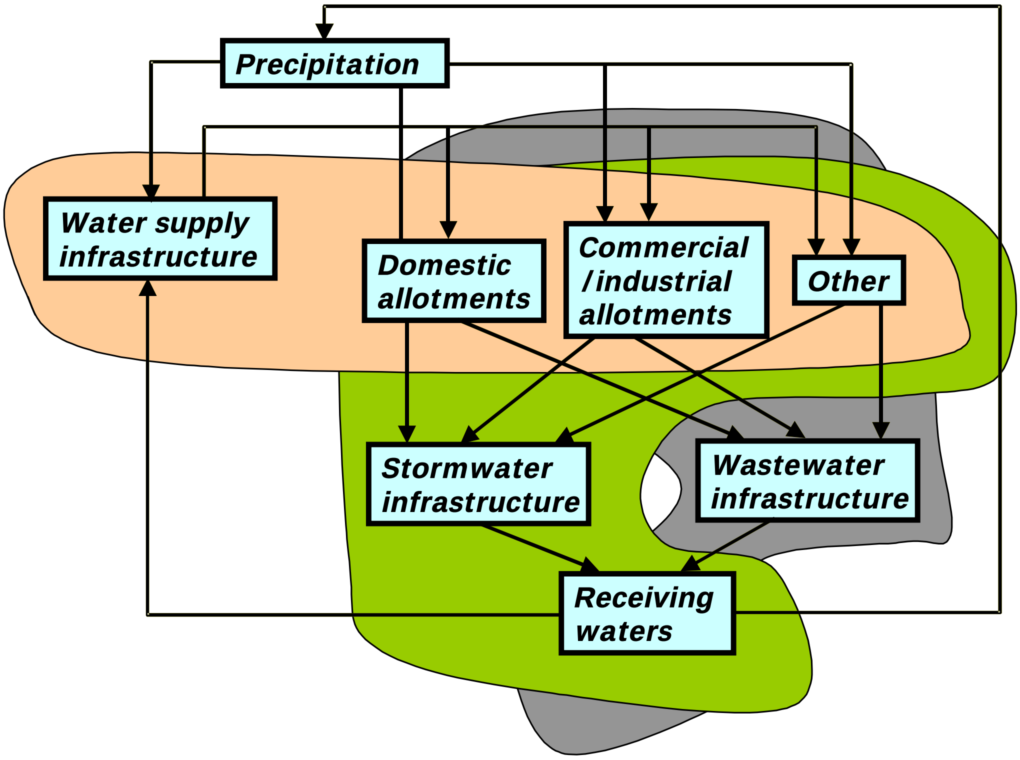

Figure 1.1: Schematic of urban water cycle depicting sub-system spheres of influences

Figure 1.1 shows the boundaries of the sub-systems responsible for water supply, stormwater and wastewater disposal. Interestingly, all three sub-systems intersect at the allotment where source control measures can be implemented. Source control measures (such as rainwater tanks) typically impact on more than one of the sub-systems. Consequently separate management of the sub-systems often obscures the benefits to the entire urban water cycle that can be derived from the use of a source control measure. Similarly resistance to the use of a source control measure by the manager of one sub-system can deprive the remaining sub-systems of benefits. The rainwater tank used on urban allotments is an excellent example of this.

In this thesis it will be argued that a systems analysis of the use of source control measures, in particular, rainwater tanks, as part of the combined stormwater management and water supply systems is required to understand their impact on the urban water cycle. It is further argued that institutionalised management of the urban water cycle as separate sub-systems has limited water cycle solutions depriving the community of substantial environmental and economic benefits that derive from the use of source control measures. A systems analysis of the urban water cycle is therefore conducted to examine the benefits of the use of source control measures at the allotment, subdivision and regional scales.

1.4 Outline of the thesis

A systems approach is used to explore the solutions that become available when the constraints imposed by institutionalisation of urban water cycle management are removed. There are many hidden or lost opportunities in urban water cycle management that are manifested in source control techniques. The opportunities created by the use of source control measures are discussed.

This thesis describes the development and performance of two demonstration sites that use source control measures for water conservation and stormwater management. The knowledge gained from these sites is employed to develop methods for the analysis of the impact of rainwater tanks used as source control measures at the allotment, subdivision and regional scales. A number of case studies are used to demonstrate the benefits of rainwater tanks at the three scales.

Chapter 2 describes the development, monitoring and performance of the Figtree Place experiment in Newcastle, Australia. Figtree Place is a 27-unit medium density development that uses infiltration, groundwater and roof water reuse methods for stormwater management and water conservation. The objective of the Figtree Place experiment was to develop an understanding of the design, social, institutional, water quality, maintenance and water use issues that result from the use of source control measures.

Chapter 3 discusses the development, monitoring and performance of the Maryville retrofit site. The knowledge gained from the Figtree Place experiment was used to install a rainwater tank to supply hot water, toilet and outdoor uses to an existing house on a small allotment in the inner city of Newcastle adjacent to a heavy industry area. The Maryville site was monitored for economic and social impact, water quality and use. The objective of the Maryville site experiment was to develop understanding of the performance of a rainwater tank at the single allotment scale.

Chapter 4 examines the water quality results from the Figtree Place and Maryville sites in the context of Australian Standards and public health policies. An analysis of historical rainwater quality, health risks and different water use scenarios is presented. The objective is to provide an understanding of the dynamics of roof, tank and hot water service rainwater quality and to present a case for acceptable rainwater reuse scenarios.

There is significant institutional resistance to the use of rainwater tanks in the stormwater disposal and water supply industries. This resistance often manifests itself in the guise of health and economic concerns. Chapter 5 explores the operation of the stormwater disposal and water supply paradigms, and the institutional resistance to the use of rainwater tanks.

Chapter 6 describes the development of an allotment water balance model to assess water conservation and stormwater management scenarios. The model operates at sub minute time scales to allow investigation of infrastructure alternatives and includes a new probabilistic behavioral outdoor water use model. The allotment water balance model is used to evaluate the performance of rainwater tanks at the allotment and cluster scale in a number of case studies. The objective of the allotment water balance model is to enable comparison of source control techniques at a time scale that will allow assessment of the impact on infrastructure provision and to allow understanding of the performance of source control measures.

Chapter 7 develops a method of analysing the performance of source control methods in subdivisions. The method uses the allotment water balance model discussed in Chapter 6 and the WUFS (Water Urban Flow Simulator) model developed by Kuczera et al. [2000]. Two case studies compare the economic, stormwater management and water conservation performance of WSUD measures (including source controls) against traditional development approaches. The objective of this chapter is to allow understanding of the impact of source control measures at the subdivision scale.

Chapter 8 introduces a new method for the estimation of regional water demand that incorporates the allotment water balance model discussed in Chapter 6 and the method of estimating non-domestic water use developed by Kuczera and Ng [1994]. The new regional demand method accounts for the water use habits at the allotment scale and allows evaluation of the impact of demand management methods including rainwater tanks. Two regional case studies are presented to demonstrate the efficacy of rainwater tanks in the management of regional water demand. The objective of the regional demand model is to include demand management measures such as rainwater tanks in a systems analysis of regional water demand.

Chapter 9 presents a case study of the Lower Hunter region's water supply system that is primarily reliant on surface and aquifer storages to provide adequate drought security. The introduction of rainwater tanks to supplement domestic mains water supply creates significant delays in the need to augment water supply infrastructure. The extent of this benefit to the community is examined. A case study of the Central Coast region's water supply system that is heavily reliant on stream diversions is also presented.

Chapter 10 discusses water supply and stormwater management economics. An investment model is developed to allow comparison between source control methods and traditional approaches at the allotment, subdivision and regional scale. A number of case studies from the previous Chapters are examined to compare the economic benefits of source control measures to traditional approaches.

Chapter 11 provides the conclusions derived from this study and recommends future research directions that result from this study.