Chapter 9

Analysis of the Water Supply Headworks Systems for the Lower Hunter and Central Coast Regions

> “There has been a shift in the climate and because of that and other factors associated with harvesting water from our rivers we are heading into crisis. Some time later this summer we will have water restrictions similar to those which were imposed during the early 90s. Rather than resort to billion dollar solutions of new dams and seawater desalination plants we should try and reduce consumption and the obvious easy and relatively low-cost solution is for everyone to install rainwater tanks. Sadly our forefathers erred when at the time of reticulation many years ago they said water tanks should be demolished” Doug Eaton, Wyong Councillor and long-term board member of the Gosford Wyong Council’s Water Authority (2001).

9.0 Introduction

The results from the monitoring of the performance of the Figtree Place and Maryville experiments revealed that the use of rainwater tanks to supplement mains water supply for hot water, toilet and outdoor uses significantly reduced the consumption of mains water (Chapters 2 and 3). In Chapter 6 it was shown that the operation of the Figtree Place and Maryville experiments would provide substantial long-term reductions in mains water use.

It was also shown in Chapter 6 that the introduction of rainwater tanks to all domestic dwellings to supply hot water, toilet and outdoor uses would provide very substantial reductions in mains water use from domestic areas in the Lower Hunter region. However the impact of the installation of rainwater tanks on regional mains water demand will depend on the implementation rates for the rainwater tanks, and the spatial variation of climatic and socio-economic conditions within a region. In Chapter 8 a regional demand model was developed to predict mains water demand in a region where rainwater tanks are also used to supplement domestic mains water supply. The regional demand model accounts for the climatic and socio-economic variation within the region and the installation rates for rainwater tanks ultimately providing replicates of future mains water demand for use in Monte Carlo water supply headworks simulation.

In Chapter 8 1,000 100-year replicates of regional mains water demand in the Lower Hunter and Central Coast regions were created for the period 2000 to 2099. It was shown that the installation of rainwater tanks at different rates would substantially reduce mains water use in the regions. In this Chapter the regional demand scenarios created in Chapter 8 will be used in the WATHNET water supply headworks model [Kuczera, 1992] to determine the impact of the installation of rainwater tanks in the Lower Hunter and Central Coast regions on the provision of water supply headworks infrastructure.

9.1 Analysis of the Water Supply Headworks System in the Lower Hunter Region

The Lower Hunter Region has a population of 455,000 people with an overall growth rate of 0.9%. Domestic water demand accounts for approximately 43% of total water demand. The region spans five local government areas, namely Newcastle, Lake Macquarie, Maitland, Cessnock and Port Stephens. The region has been divided into nine zones to facilitate water supply modelling and is dependant on surface water and groundwater storages for water supply.

9.1.1 Description of the Lower Hunter Water Supply Headworks System

A schematic of the Lower Hunter region water supply headworks system is presented in Figure 9.1. The system presently consists of two major surface reservoirs that harvest water from the Williams River catchment and a sub-surface reservoir, the unconfined aquifer of the Tomago Sand Beds.

The Chichester Reservoir has a capacity of 21,500 megalitres (ML). Current environmental flow constraints for the Chichester River require all streamflows below 14 ML/day to be released from the reservoir. A gravity pipeline delivers up to 95 ML/day to the region via the Dungog treatment plant.

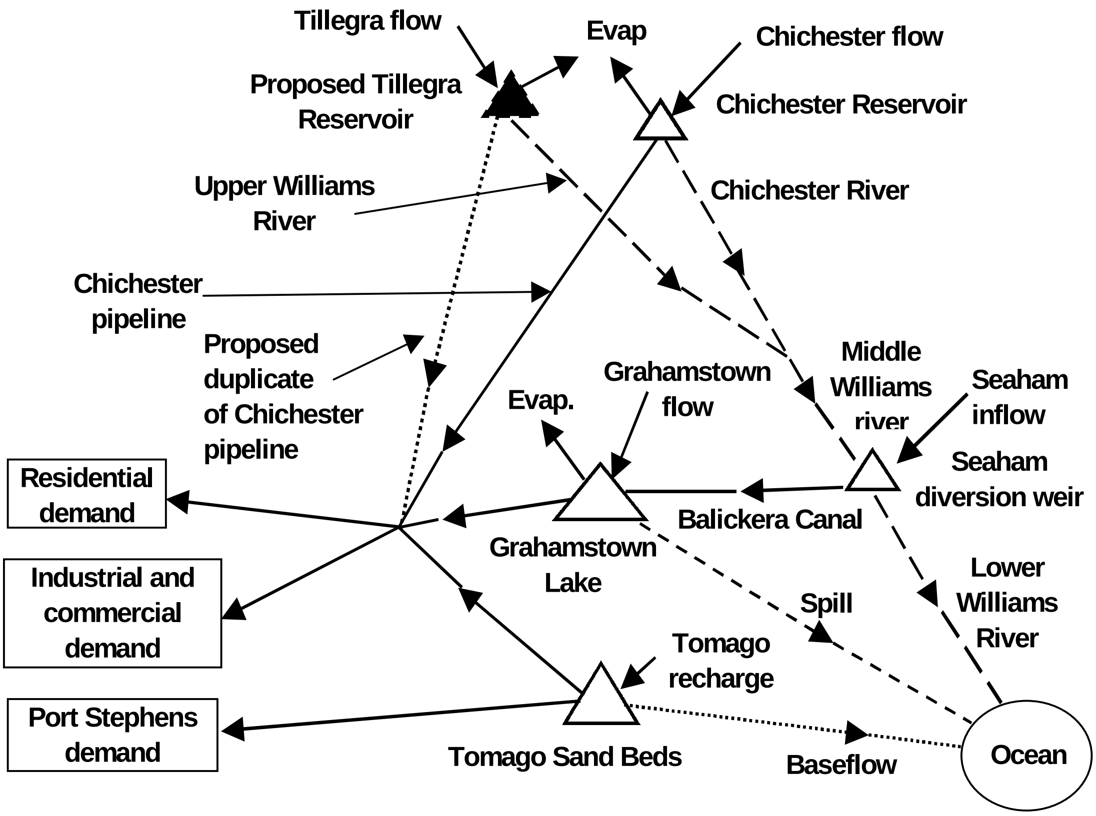

Figure 9.1. Schematic of Lower Hunter water supply headworks system

The Seaham diversion weir is used to divert water from the Williams River into Grahamstown reservoir via the Balickera pumping station and canal. The pumping station has a maximum capacity of 1,330 ML/day. At low streamflows water quality and environmental constraints limit pumping from Seaham weir. The peaky nature of high streamflows in the Williams River also limits the volume of water that can be pumped from Seaham weir.

The final stage of Grahamstown Lake with a capacity of 198,200 ML has been used in the study. It is supplied with water via diversions from Seaham Weir and local runoff from a catchment with an area of 99 km^2. Water from the lake is distributed to the region via the Tomago treatment plant. The Tomago Sand Beds is an extensive unconfined aquifer with a storage capacity of approximately 232,800 ML. Water from the Sand Beds is used to supplement water from the Williams River system. When the combined capacity of Chichester and Grahamstown reservoirs falls below 80% up to 100 ML per day is drawn from the Tomago Sand Beds.

All domestic, industrial and commercial water demand (except Port Stephens) in the Lower Hunter region is supplied from Chichester reservoir, Grahamstown Lake and the Tomago aquifer. This study only considers water demand from the Port Stephens area that is drawn from the Tomago aquifer. The majority of water demand in the Port Stephens area is sourced from local (Tomaree) aquifers.

9.1.2 Streamflow and Evaporation

The data supplied by the HWC and used to create 1,000 100-year replicates of future streamflow, climate and evaporation data for use in the water supply headworks and demand (Chapter 8) modelling is summarised in Table 9.1. Historical streamflow and evaporation data for the period 1931 to 1996 was provided by HWC [B. Berghout, personal communication, 1999] and the climate data was provided by the New South Wales office of the Bureau of Meteorology.

Table 9.1: Streamflow, evaporation and climate data from the Lower Hunter region

Description	**Annual mean**	**Std. Dev.**	**Skew**	**Lag-1 Cor**
Mill Dam gauge	332,295 ML	247,195 ML	1.087	0.214
Chichester River gauge	96,287 ML	62,791 ML	0.911	0.123
Tillegra River gauge	95,886 ML	63,519 ML	0.9	0.146
Chichester evaporation	47.55 mm	20.26 mm	-	-
Grahamstown evaporation	76.27 mm	29.17 mm	-	-
Grahamstown runoff	10,489 ML	2,693 ML	0.679	0.178
Tomago recharge	47,267 ML	26,551 ML	1.037	0.207
Chichester rainfall	1,287 mm	353 mm	0.6	0.097
Grahamstown rain	1,055 mm	271	0.679	0.178
Williamtown air temperature	22.7 ºC	0.61 ºC	0.418	0.388
Cessnock rainfall	715 mm	204 mm	0.679	0.287
Cessnock rain days	6 days/month	1.36 days/month	0.373	0.378
Cessnock air temperature	23.7 ºC	7.99 ºC	0.753	0.282
Charlestown rainfall	1,009 mm	251 mm	0.492	0.166
Charlestown rain days	13 days/month	2.02 days/month	0.248	0.326
Newcastle air temperature	21 ºC	6.98 ºC	0.334	0.619
Maitland rainfall	898 mm	251 mm	0.749	0.214
Maitland rain days	11 days/month	1.73 days/month	0.641	0.232
Maryville rainfall	1,121 mm	275 mm	0.832	0.285
Maryville rain days	11 days/month	1.83 days/month	0.648	0.285
Port Stephens rainfall	1,255 mm	357 mm	0.892	0.182
Port Stephens rain days	12 days/month	1.8 days/month	0.057	0.159
Toronto rainfall	1,178 mm	305 mm	0.551	0.18
Toronto rain days	12 days/month	2.08 days/month	0.337	0.41

The 1,000 replicates of the streamflow, climate and evaporation summerised in Table 9.1 were generated for the period 2000 to 2099 using the methods described by Kuczera [1992] that employ the multisite lag-one Markov model [Matalas, 1967] to generate annual values that were then disaggregated into monthly values using the method of fragments [Svanidze, 1960]. The replicated climate data was used in the regional demand model (Chapter 8) to simulate the regional water demand to be satisfied by the headworks infrastructure.

The replicated monthly values for streamflows at the Mill Dam, Chichester and Tillegra gauges are used in the water supply headworks model to account for Chichester and Tillegra flows, and Seaham inflows shown in Figure 9.1. The replicated values for Chichester Reservoir and Grahamstown Lake evaporation are used to simulate the evaporation from Chichester Reservoir and Grahamstown Lake during each month in the water supply headworks model. The replicated values for Chichester evaporation are also used to simulate evaporation from the proposed Tillegra reservoir in the headworks model. The replicated values for Grahamstown runoff are used to simulate stormwater runoff from the Grahamstown catchment to Grahamstown Lake and the replicated values for Tomago recharge are used to simulate the rainfall recharge of the Tomago aquifer in the water supply headworks model.

9.1.3 Augmentation Strategy

In this study, reliability was defined as the probability that water restrictions will not be imposed in a particular year. Restrictions on demand are triggered when the combined storage of Chichester Reservoir and Grahamstown Lake falls below 60%.

When the reliability of the system falls below 90% HWC's operating licence requires that the system be augmented. In this study following the recommendation of Hunter District Water Board [1982], augmentation consists of construction of a reservoir on the Williams River at Tillegra. The augmentation strategy has two stages:

- Stage 1: If reliability falls below 90%, build Stage 1 of the Tillegra reservoir (Figure 9.1) with a capacity of 240,000 ML together with installation of pumps to increase the hydraulic capacity of the Chichester pipeline at a cost of $103.7M (in year 2000 dollars).
- Stage 2: If reliability falls below 90% after completion of Stage 1, construct a water supply pipeline from Tillegra Reservoir at a cost of $101.7M

9.1.4 The WATHNET Water Supply Headworks Model

The drought security of the Lower Hunter water supply headworks system was assessed using WATHNET [Kuczera, 1992] for different household demand scenarios. WATHNET is a suite of programs for generalised water supply headworks simulation using network linear programming. In the programs a water supply headworks system is operated at seasonal time steps in accordance with the following hierarchy of objectives [Kuczera, 1997]:

1. Satisfy water demand at all demand nodes (rules may be used to restrict demand);
2. Satisfy all instream flow requirements;
3. Ensure that reservoirs are at their end-of-season target volumes;
4. Minimise water delivery costs; and
5. Avoid unnecessary spill from the system.

WATHNET maintains a mass balance at each node in the system and using historical or replicated streamflow, evaporation and demand data runs a network linear program that assigns water according to the above objectives. The network linear formulations can be solved using the NETFLO simplex algorithm [Kennington and Helgason, 1980] or the RELAX algorithm [Bertsekas, 1991].

Seven different nodes and two arcs are available in WATHNET to allow the construction of a model of a water supply headworks system. The different types of nodes include reservoirs, demands, gravity diversions, pump diversions, conduit junctions, stream junctions and a waste node. The two arc types are streams and conduits. An extensive range of options is available to control arc behaviour.

9.1.5 Impact of Rainwater Tanks on Augmentation Timing for the Lower Hunter Region

Table 9.2 summarises the timing of the water supply augmentation required to maintain reliability at or above 90% for each of the demand scenarios described in Chapter 8. The water supply network used in WATHNET and the results of the simulations are shown in Appendix J.

Table 9.2. Years in which augmentation of water supply is required

Augment stage	**Augmentation required for scenario (year)**							
	Base	**Growth**	**G+0.25%**	**G+0.5%**	**G+0.75%**	**G+0.9%**	**G+2%**	**G+3%**
1	2041	2049	2050	2055	2064	2067	2075	2075
2	NR	NR	NR	NR	NR	NR	NR	NR

Note: NR indicates augmentation was not required.

The installation of rainwater tanks on all new and redeveloped domestic dwellings (This corresponds to the G+0.9% scenario because the housing redevelopment rate in the Lower Hunter region is about 0.9%) will delay the construction of the Tillegra Reservoir by 26 years. Local Government in the Lower Hunter region require additional stormwater management measures on redevelopment sites. Rainwater tanks could be installed for stormwater management on new and redeveloped dwellings resulting in reduced costs for stormwater management (Chapter 7) and ultimately providing a 26-year delay in the requirement for the Tillegra reservoir. The introduction of rainwater tanks is shown to delay augmentation from 8 to 34 years depending on the rate of rainwater tank adoption. Installation of rainwater tanks on all new domestic dwellings in the Lower Hunter region will delay the requirement to construct the Tillegra reservoir by 8 years.

Domestic water demand is only a small portion (43%) of total demand in the Lower Hunter region. Even greater delays in the construction of new water supply headworks infrastructure will be experienced in areas with similar climate and with domestic demand that forms a greater proportion of total demand.

9.2 Analysis of the Water Supply Headworks System for the Central Coast Region

In this Section the impact of rainwater tanks on the Central Coast water supply headworks system where domestic water demand accounts for approximately 62% of total water demand is examined. The Central Coast region has a population of 289,100 people with a growth rate of 1.37% that is expected to slow to 0.24% after the year 2030. The region includes two local government areas, namely Gosford and Wyong. The region has been divided into two zones to facilitate water supply modelling.

9.2.1 Description of the Central Coast Water Supply Headworks System.

A schematic of the Central Coast region water supply headworks system is presented in Figure 9.2. The system presently includes a major surface reservoir on Mangrove Creek and harvests water from the Mangrove Creek, Mooney Mooney Creek, Ourimbah Creek and Wyong River catchments. Mangrove and Mooney Mooney Creeks discharge to the Hawkesbury River. Ourimbah Creek and Wyong River discharge to the Tuggarah Lakes.

Mangrove Dam has a storage capacity of 195,000 ML. Gosford/Wyong demand is met by releasing water from Mangrove dam into Mangrove Creek that is pumped from Mangrove Weir to the Somersby Transfer system at a maximum rate of 25,376 ML/month. Water is also pumped from the Mooney Dam on Mooney Mooney Creek via the Somersby Transfer System at a maximum rate of 16,470 ML/month.

Water from the Wyong River (maximum rate: 21,960 ML/month) and Ourimbah Creek (maximum rate: 17,080 ML/month) is pumped to the Mardi Transfer system via Mardi Dam to supply Gosford/Wyong demand.

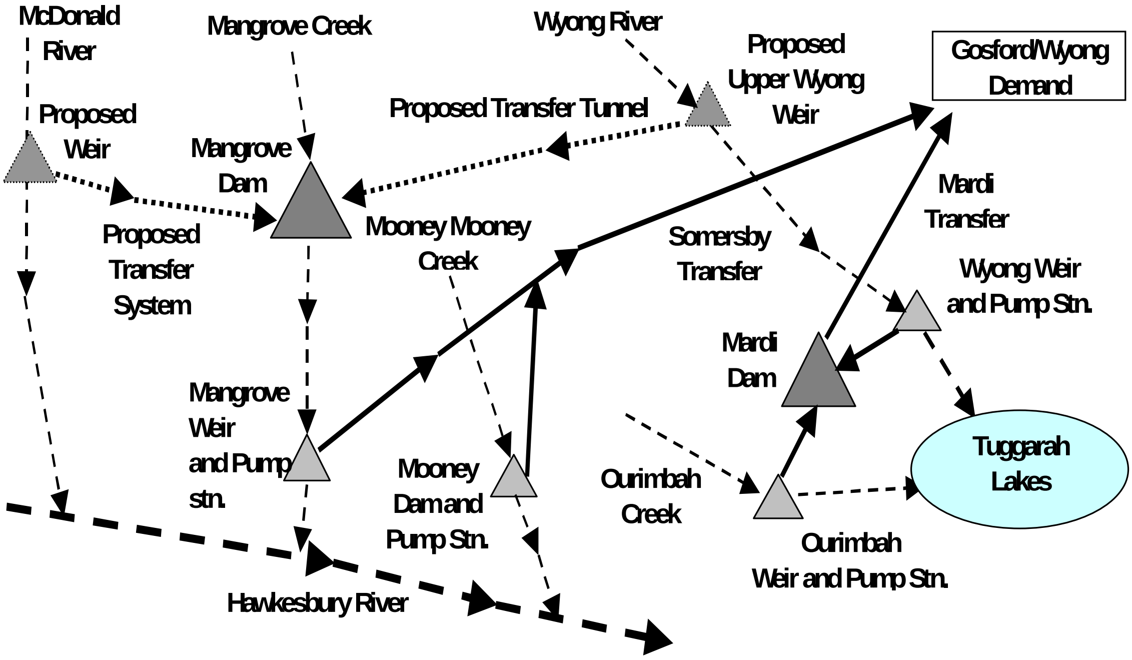

Figure 9.2: Central Coast water supply headworks system.

9.2.2 Streamflow and Evaporation

The Gosford and Wyong Councils' Water Authority has an ongoing desire to optimise management of its system planning process for water supply to the Central Coast region.

Primary goals in the management of the water supply are to maximise reliability and minimise operating costs. This can be achieved by development of an understanding of the hydrological processes and the resulting streamflows in the water supply catchments. Unfortunately only short-term streamflow records were available from the Department of Land and Water Conservation (Table 9.3) and these records were not at locations of interest for management of the water supply headworks system.

Table 9.3: Available streamflow data in the Central Coast region prior to 1996

Station	Period available	Missing data
Tuggerah - Ourimbah Creek	1965 - 1989	5 months, a few weeks
Wyong Weir - Wyong River	1966 - 1971	29 days
Gracemere - Wyong River	1972 - 1996	1 month, a few weeks
Jilliby Creek - Wyong River	1972 - 1994	1 month
Yarramalong - Wyong River	1976 - 1996	3 months, a few weeks
Wyong Creek - Wyong River	1925 - 1933, 1942 - 1955	1 month
Fairview - Mangrove Creek	1970 - 1991	4 months, a few weeks
Mangrove Dam - Mangrove Creek	1976 - 1992	3 months
St. Albans - MacDonald River	1954 - 1990	9 months, a few weeks

The Snowy Mountains Engineering Corporation (SMEC) was commissioned by the Gosford and Wyong Councils' Water Authority in 1984 and 1996 to obtain estimates of streamflow at preferred locations (Table 9.4), extend the length of streamflow records to about 35 years coinciding with the period of available inland rainfall data and provide an evaporation record for Mangrove Dam of similar length [SMEC, 1996].

The Monash model [Porter and McMahon, 1976] was employed by SMEC in 1984 to establish streamflow records at desired locations (Table 9.4) and to extend the length of streamflow records to about 35 years. In 1996 SMEC used the MODHYDROLOG model [Chiew and McMahon, 1994] to repeat the task. Evaporation records were extended using data from the Prospect Reservoir in the nearby Sydney water supply catchment. In this study the records provided by SMEC [1996] have been extended from 1996 to 1998 by the addition of subsequent monitoring data. Climate data was added to the data set to facilitate demand modelling (see Chapter 8).

The streamflow, climate and evaporation data (Table 9.4) was then fitted to a multi-site probability model to obtain model parameters and distributions. One thousand replicates of the streamflow, climate and evaporation shown in Table 9.4 were generated for the period 2000 to 2099 using the methods described by Kuczera [1992] that employ the multisite lag-one Markov model [Matalas, 1967] to generate annual values that were then disaggregated into monthly values using the method of fragments [Svanidze, 1960]. The replicated climate data was used in the regional demand model (Chapter 8) to simulate regional demand to be satisfied by the headworks system.

Table 9.4: Extended streamflow, evaporation and climate records at desired locations in the Central Coast water supply catchment

Location	Annual Mean	Std. Dev.	Skew	Lag-1 Cor.	Period
Ourimbah Creek at Weir (ML)	30,737	21,184	0.843	0.161	1967 - 1998
Wyong River at proposed upstream weir (ML)	46,973	32,379	0.951	0.251	1960 - 1998
Wyong River at lower weir (residual) (ML)	51,913	38,632	0.96	0.167	1967 - 1998
Mangrove Creek at dam (ML)	23,856	18,807	1.091	0.326	1960 - 1998
Mangrove Creek at weir (residual) (ML)	29,664	18,300	1.094	0.513	1960 - 1998
Mooney Mooney Creek at dam (ML)	9,254	6,767	1.411	0.096	1967 - 1998
Evaporation (mm)	1,265	174.5	-0.154	0.721	1960 - 1998
Kulnara North rainfall (mm)	1091	316	0.449	0.051	1960 - 1998
Gosford rainfall (mm)	1339	393	0.432	-0.1	1960 - 1998
Gosford rain days	10 days/ month	1.46 days/ month	-0.409	-0.164	1960 - 1998
Gosford air temperature	22.9 ºC	5.25 ºC	0.207	-0.148	1960 - 1998
Wyong rainfall (mm)	1,214	318	0.409	-0.003	1960 - 1998
Wyong rain days	11 days/ month	1.56 days/ month	0.009	-0.037	1960 - 1998
Wyong air temperature	24.2 ºC	7.24 ºC	0.54	-0.146	1960 - 1998

9.2.3 The Augmentation Strategy for the Central Coast Water Supply Headworks System

The reliability of the headworks system was defined as the probability that storage in Mangrove Dam will not be fall below 20% in a particular year. When the reliability of the system falls below 99% current policy requires that the system be augmented [Grimster, GWCWA, personal communication, 2000]. The augmentation strategy used in this case study is adapted from the recommendations of the adjoining Hunter District Water Board [1982] and GWCWA and is in two stages:

Stage 1: Construction of a Wyong River to Mangrove dam transfer system (Figure 9.2) at a cost of $76.4M (in year 2000 dollars), and

Stage 2: Construction of a McDonald River to Mangrove dam transfer system (Figure 9.2) and increase the capacity of Mangrove dam by 455,000 ML at a cost of $194.5M.

9.2.4 Impact of Rainwater Tanks on Augmentation Timing for the Central Coast Region

The drought security of the Central Coast water supply headworks system was assessed using WATHNET [Kuczera, 1992] (Section 9.1.4) using different household demand scenarios provided using the Regional Demand Model (Chapter 8) and synthetically generated streamflow replicates for the period 2000 to 2099. Table 9.5 summarises the timing of the water supply augmentation required to maintain reliability at or above 99% for each of the demand scenarios. The water supply network used in WATHNET and the results of simulations are shown in Appendix J. The symbol NR indicates augmentation was not required. Introduction of rainwater tanks delays Stage 1 augmentation by 28 for the Growth scenario to 36 years for the G+0.5% scenario. The requirement for Stage 1 augmentation is eliminated altogether for scenarios greater than G+0.5%. The use of rainwater tanks also eliminates the need for Stage 2 augmentation.

Table 9.5: Years in which augmentation of water supply is required

Augment stage	**Augmentation required for scenario (year)**						
	Base	**Growth**	**G+0.25%**	**G+0.5%**	**G+0.75%**	**G+0.9%**	**G+2%**
1	2026	2054	2058	2062	NR	NR	NR
2	2062	NR	NR	NR	NR	NR	NR

Installation of rainwater tanks on all new domestic dwellings in the Central Coast region will delay the requirement for new water supply headworks infrastructure by at least 28 years. The installation of rainwater tanks on all new and redeveloped domestic dwellings (The G+0.9% scenario because the housing redevelopment rate in the Central Coast region is about 0.9%) will delay the construction of new water supply headworks infrastructure for more than 100 years.

The use of rainwater tanks has produced larger delays in the requirement to provide new water supply infrastructure than in the Lower Hunter region because the domestic consumption as a proportion of total consumption is greater in the Central Coast region than in the Lower Hunter region. The use of rainwater tanks in the Sydney, Brisbane and

Melbourne regions may also result in considerable delays in the requirement for new water supply infrastructure because the domestic consumption as a proportion of total consumption in those cities is similar to that in the Central Coast region.

9.3 Why the Widespread Introduction of Rainwater Tanks Can Defer the Requirement for New Dams

The conventional wisdom is that rainwater tanks are of little benefit to the community because during drought the rainwater tank is empty and the consumer is totally reliant on mains water. This wisdom, like that about the safety of rainwater tanks (Chapter 4), appears to be based more on belief than fact. In this Chapter it was shown that the widespread introduction of rainwater tanks to supply hot water, toilet and outdoor uses will defer the requirement for new dams in the Lower Hunter and Central Coast regions. Conventional wisdom appears to be at odds with the results presented in this thesis. There are a number of “hidden” processes by which rainwater tanks significantly reduce impact on water supply headworks systems. These are described below.

It is true that during drought major urban water supply systems rely on water storages. For example on the east coast of Australia droughts represent extended periods of below average rainfall. In the last 150 or so years the annual rainfall at Sydney’s Observatory Hill has dipped a few times to between 600 to 700 mm. Figure 9.3 presents a schematic comparing the efficiency of a water supply catchment and a roofed catchment feeding a rainwater tank. Plots of annual runoff against annual rainfall for water supply catchments typically display a threshold effect. Once annual rainfall falls below about 500 mm annual runoff in water supply catchments is insignificant. In such years evapotranspiration and infiltration accounts for virtually all of the rainfall and the water supply system is almost totally dependent on water stored from more bountiful years. In contrast the roofed catchment, being impervious, only experiences a small loss at the commencement of each rain event. As a result, a rainwater tank can harvest significant volumes of water even during drought years.

Conventional wisdom assumes that rainwater tanks in urban areas only provide water for outdoor uses such as garden watering. As a result, the tank is only utilised during the growing season. If, however, the tank is used for toilet flushing and hot water, which represent a significant fraction (about 60%) of indoor usage, the tank is constantly being drawn down. This has two unexpected benefits. First, for small storm events much of the potential runoff is captured by the tank – that is why use of the rainwater tank produces such good results for small ARI storm events shown in Chapters 6 and 7. Second, because toilet flushing and hot water are sourced from the rainwater tank, the base load on the mains water system is reduced. As a result, reservoirs will fill more rapidly during periods of good streamflow. In headworks systems with over-year storage capacity, the reduction in base demand provides a buffer against the effects of droughts and growth in water demand due to population growth.

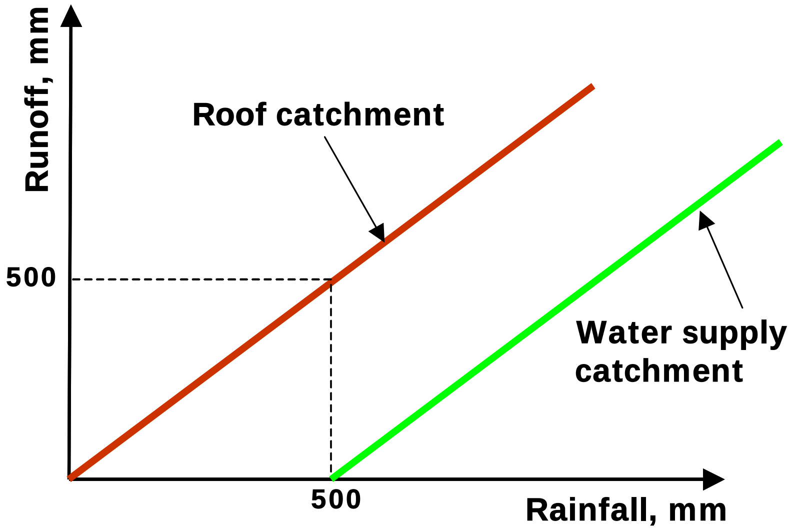

Figure 9.3. Harvest efficiencies of natural and roofed catchments.

9.4 Summary

In this Chapter the demand scenarios developed in Chapter 8 were used in the WATHNET [Kuczera, 1992] water supply headworks model to determine the impact of the installation of rainwater tanks on the provision of water supply headworks infrastructure in the Lower Hunter and Central Coast regions.

It was demonstrated that the use of rainwater tanks to supply outdoor, hot water and toilet flushing demand will delay construction of new water supply headworks infrastructure from 8 years to 34 years in the Lower Hunter region. The installation of rainwater tanks to all new domestic dwellings will delay the requirement for a new dam by 8 years and the installation of rainwater tanks to all new and redeveloped domestic dwellings will delay the requirement for a new dam by 26 years. The installation of rainwater tanks to meet Local

Government requirement for additional stormwater management on new and redevelopment sites will produce a significant dual benefit.

Domestic water demand is only 43% of total water demand in the Lower Hunter region. In areas with domestic demand that is a greater proportion of total demand and with similar climate even greater impacts on deferral of the requirement for new dams was expected. The impact of rainwater tanks on the Central Coast water supply headworks system was examined. It was demonstrated that the use of rainwater tanks to supply outdoor, hot water and toilet flushing demand in the Central Coast region will delay construction of new water supply headworks infrastructure by a minimum of 28 years and, in some cases, eliminate the requirement for new dams in the next 100 years. Specifically, the installation of rainwater tanks to all new domestic dwellings will delay the requirement for a new dam by 28 years and the installation of rainwater tanks to all new and redeveloped domestic dwellings will eliminate the requirement for a new dam.

In conclusion it was shown that the installation of rainwater tanks can delay the requirement to construct new dams, be reducing domestic mains water use, reduce the requirement for stormwater management infrastructure and reduce environmental impacts. What economic benefits flow to the community from widespread installation of rainwater tanks? This question is taken up in Chapter 10.