A Water Cycle Management Strategy for Local Government

Masters of Science (MSc by Thesis)

By

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Certificate of Authorship

I certify that this thesis has not already been submitted for any degree and is not being submitted as part of candidature for any other degree.

I also certify that this thesis has been written by me and that any assistance in the preparation of this thesis has been acknowledged in this thesis.

This thesis is subject to the University procedures and requirements. Harvard UTS referencing style has been used in the preparation of this thesis.

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Acknowledgments

When I commenced this project I did not know what to expect or what approach to take, and admittedly I was apprehensive and not really prepared for the task ahead.

It soon became apparent that researching science can be enjoyable, and also very frustrating. But I was very fortunate that I had very supportive, knowledgeable and experienced supervisors guiding me.

Firstly, my thanks go to my principal supervisor Associate Professor Kenneth Brown for his wisdom and unique approach of turning negative issues into positive outcomes for this I'm truly grateful and wish him a happy and fulfilled retirement. Secondly, my gratitude and thanks go to my co-supervisor Dr Ross McPherson for his ongoing support, continual feedback, enthusiasm, encouragement and friendship. I would also like to thank Mrs Katie Clarke for her assistance and untiring patience and my employer Hornsby Shire Council for assistance and support.

Finally, I would like to dedicate this thesis to my mother, Elli, for her life long support in my endeavours. My thanks also go to my family, Effy, Chris, Dino, Shireen, Floria and my nieces Rachael and Breanna for their encouragement and support.

"I hear … and I forget

I see …and I remember

I do … and I understand".

…….*Anonymous*

Abstract

Management of the water cycle on a strategic level has been very limited in local government. Local governments are major stakeholders in frontline environmental management and collectively they have a major influence on how natural resources are managed nationally. Their management role of regulating development and town planning has a major effect on the water cycle.

The ecological characteristics of the hydrological cycle involve a broad and complex hydrological regime that influences the natural environment through its integration of climate, geology, geomorphology, groundwater, evaporation, transpiration and precipitation.

The aim of this research is not to propose or uncover new scientific knowledge on the workings of the hydrological cycle, but to acknowledge current research, and apply principles into a management process. The research further recognises the principal ecological components that regulate the water cycle in a local government context through development regulation and the management of natural resources. As a result, this research proposes a Water Cycle Management Strategy template that can be applied by local government to manage the water cycle.

The increasing demands on water resources will exceed our ability to supply this valuable resource in the near future. The rectification of this situation will require improved decision-making using holistic strategies in water resource planning. An integrated/ multidisciplinary management approach from the catchment headwaters to the household incorporating temporal and spatial factors needs to be considered to manage the water cycle. Managing urban development impacts and maintaining an ecological water balance through the principles of sustainability and equity of water resources is a priority.

This research project encapsulates a water cycle strategic framework that focuses on achieving sustainable outcomes for water cycle management within local government. The Strategy encompasses low, medium and high priority objectives that integrates science with strategic management. The strategic framework includes; an assessment of the water cycle, management of human induced impacts and the conservation of water resources which incorporates environmental, social, and economic considerations.

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1.0 Introduction

Life on Earth has depended on the water cycle since the first single-cell organisms appeared billions years ago. The sustainability of life on Earth and our economic prosperity depends on the availability of water resources. One of the greatest challenges facing humanity is sourcing and maintaining a reliable water supply to sustain the existence of urban and natural environments.

Fresh water demands are continually increasing globally in response to population growth, as a result pollution has increased within our streams and rivers (Chanan & Woods 2005). The issues which need to be addressed are: do we manage water resources effectively to satisfy our growing demands or is it mismanagement. Emerging trends are beginning to show that much of the demand for water is primarily the result of mismanagement of water resources (Cosgrove & Rijsberman 2000).

To address these concerns, water resource strategies need to have a balanced and holistic approach to environmental, social and economic management. Such management approaches need to combine prediction, acknowledgment of uncertainty, adaptability and be flexible to accommodate change, advancement in science innovation and political trends. However, before management can determine what strategies are best suited for any desired outcome, authorities and community stakeholders must have a collective vision that will achieve sustainable outcomes supported by factual science.

1.1 Rationale

Traditionally environmental science and management strategies tended to be dealt with individually. Generally, science programs tend to focus on a hypothesis supported by experimental design, collection of data and statistical analyses centred on one ecological aspect of the environment (i.e. water quality, saltmarsh, microfauna, macroinvertebrates etc) with minimal appreciation of the "big picture" (Ashton et al. 2005). In addition sampling and experimental programs have become large, complex, unclear in their data interpretations, and often very costly and difficult to extract reliable outcomes from the "noise" in data which can result in inadequacies in the assessment of the natural environment (Underwood 1981, 1997).

In contrast, environmental management approaches lack depth, direction and understanding of the environment that can only be provided by scientific research. Conversely, the science paradigm is shifting from supporting policy and providing decision information systems (i.e.modelling) to managing natural resources in consultation with stakeholders (Dube et al. 2006). This project does not propose new scientific knowledge on the workings of the hydrological regime, but to acknowledge current research in strategic processes and methodologies for managing the water cycle in an ecologically sustainable manner that integrates science and management methodologies for local government.

1.2 The Hydrological Cycle

The age of the earth is believed to be 4.6 billion years. The oldest known rocks to have shown the presence of water on the earth have been dated as 3.8 billion years (Berner & Berner 1987).

During the period between 4.6 and 3.8 billion years ago no water existed because no rocks dated during this period have shown the presence of water nor would such rocks be found since there will be a high probability that these rocks would have been destroyed by erosion or metamorphism (Berner & Berner 1987). This theory is based on the meteoritic formations period that presumably formed the earth simultaneously from stony meteorites, comprised of the *carbo-naceous chondritis* with 20 per cent water locked in the structure of minerals, particularly in clay minerals in the form of hydroxyl ions (OH-). The *carbonaceous chondritis* are debris left over from when the solar system originally formed, it provides credible evidence on the origins of how water was added to the earth (Berner & Berner 1987).

Other related theories have shown that comets made mostly of ice and weighting 20 to 40 tons were drawn into the Earths gravity at a rapid rate of thousands per day then proceeded to melt and vaporised within the atmosphere. If this process were constant over a period of 20,000 years, the comets would have provided enough moisture to cover the entire surface of the Earth with 2.5cm of water every 20,000 years (Hunt 2004b).

Other common theories suggest that the origins of water are a product of the thermonuclear fusion processes that produced the elements of the periodic table. These theories suggest that water on Earth may have originated from the degassing or outgassing of the planet's mantle by volcanic eruptions and surfacing lava (Maidment 1992a). This process cooled over time producing water vapour in the atmosphere and subsequently condensed to form the oceans. A belief is the degassing of the volcanic reactions may have and continues to, regenerate the hydrological cycle today. The volume of "new" water being regenerated is believed to be approximately one km^3 over a five billion year life span of the Earth (Hunt 2004b).

The Hydrological Cycle (Water Cycle) as shown in Figure 1 is one of the essential processes for sustaining life for all organisms on the earth. The natural process is unique in that it encompasses all physical states on the Earth. Of the 2.5 percent freshwater available only 0.5 percent is available for human consumption ('The Value of Water: Inquiry into Australia's Urban Water Management' 2002).

The water cycle can be systematically viewed in the following phases:

- liquid and ice evaporate from the ocean and land into the atmosphere;
- water vapour is transported through the atmosphere by winds;
- water vapour condenses into cloud droplets and crystals;
- cloud particles aggregate by accumulation into larger liquid and solid drops that fall as precipitation to the surface; and
- rivers, aquifers and ocean currents transport the water through land and ocean reservoirs.

A more descriptive definition illustrates the process shown on Figure 1, as a

> …continuous and complex transfer of water through its gaseous, liquid and solid states from the oceans to the land. Water is evaporated from the oceans into the atmosphere and transported by winds to the lands where the air condenses and falls as precipitation. Once on the ground, the remaining water finds its way back to the sea via evaporation from the land surface, evapo-transpiration from vegetation, runoff from rivers and groundwater movement …(Jones et al. 1990, pp. 221-222).

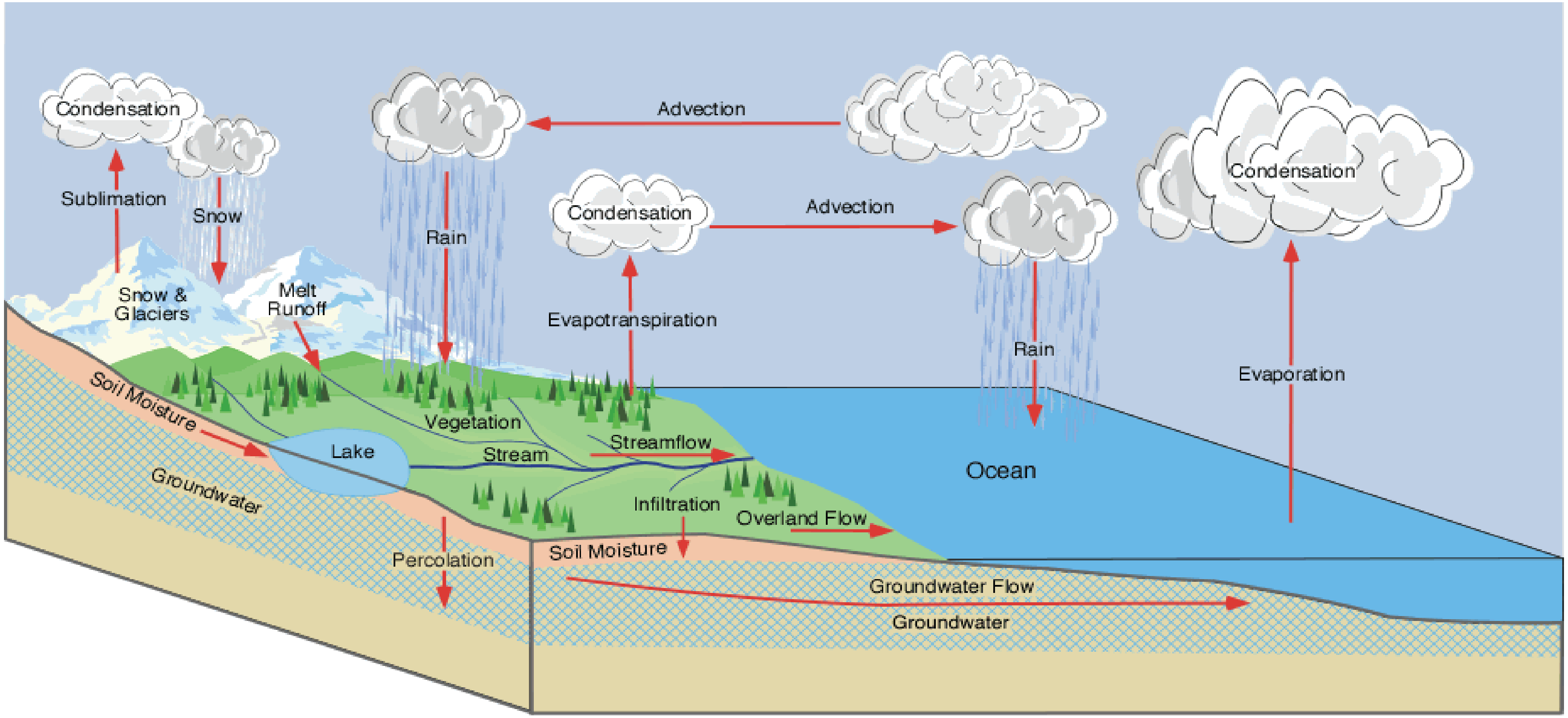


Figure 1: Illustrates the hydrological cycle is a continuous and complex transfer of water through its gaseous, liquid and solid state processes involving water evaporation from the oceans, rivers and vegetation, into/from the atmosphere, transported by winds overland where the air condenses and water falls as runoff and percolates and filters through the earth's surface to groundwater storage (aquifers) feeding rivers and flowing back into the sea (Adapted from Pidwirny & Habbart 2007).

Properties of Water

Water is a liquid which in an impure state constitutes rain, oceans, lakes, aquifers, estuaries and rivers. An important water characteristic is its remarkable solvent capability which allows it to be transported via biochemical processes as gases in the atmosphere and re-radiate as solar emissions by the sun. Water in a pure state is a transparent, odourless, tasteless liquid and a compound of hydrogen and oxygen, H_2O, freezing at 0°C, and boiling at 100°C. It's composition is 11.188 per cent hydrogen and 88.812 per cent oxygen, by weight" (Delbridge & Bernard 1996). Water exhibits many unusual qualities, ranging from physical to chemical properties which influence the water cycle globally. The density of water can be affected by temperature, decreasing as the temperature increases above 4ºC, for example lukewarm water floats above colder water. As the temperature decreases below 4ºC water becomes less dense and upon freezing it expands. Materials dissolved or suspended in water such as salt or sediment will affect its density, as a result fresh water will float above saline water in estuarine environments or where saline groundwater enters a river (Gordon, McMahon & Finlayson 1992).

Processes of the Water Cycle

The water cycle processes of precipitation, interception, transpiration, infiltration, percolation and evaporation are heavily influenced by the natural environment and anthropogenic interactions (Figure 1). In basic terms the natural process is a constant interchange of water between the lithosphere (inner solid core), the hydrosphere (surface, oceans, rivers and lakes) and the atmosphere. Above the surface, water evaporates from the oceans and conversely precipitates as droplets of liquid water onto the land and infiltrates back to the sea in a continual recycled process of transfer of water from one region to the next (Dumenil-Gates, James & Batiza 2004; Green 1979).

The movement of water within the cycle is controlled by three processes - energy, transfer and infiltration. Energy (solar radiation) changes water liquid from the oceans to gas vapour in the atmosphere, as the temperature increases, water molecules become suspended in the atmosphere as vapour. Movement of air mass involving the transfer of heat is the process of advection (Allaby 1996). Atmospheric heating between land and sea masses remains constant by air pressure and winds. This occurs because air pressure over the land surface is generally lower than over the sea, the role of winds equalises this imbalance by moving the heavier, denser air from the sea to the land (Green 1979).

As rainfall lands on the surface it interacts and infiltrates the surface with biotic (living) and abiotic (non-living) components of the biosphere were it sustains life. Evaporation over the oceans exceeds precipitation, the difference results in runoff from the land (Berner & Berner 1987). The saturation of rainfall results in runoff of water were it can be diverted by the landscape of catchments that generate flows of surface runoff into streams, lakes, rivers, estuaries, and ultimately back to the sea. Minimal groundwater flows directly to the ocean, the remaining portion of precipitation on the continents is returned directly to the atmosphere via evaporation and transpiration.

Precipitation and Evaporation

Principally evaporation occurs when solar energy coverts water into vapour. As rainfall lands on the surface it can follow several pathways, some of the water will remain as droplets on vegetation or remain on the surface and evaporate under solar radiation.

The water cycle is driven constantly by the process of solar energy evaporation from the oceans to land and is influenced by the varying temperatures of cold ocean current movements. As a result water vapour condenses as it cools, thus reducing the amount of water vapour that air can hold. This reaction results in a moisture saturation level whereby air temperature is at the dew point. Further increases in cooling and altitude will result in condensation and precipitation (Hunt 2004b).

The rate of cooling is referred to as the adiabatic rate, which depends on how much water vapour is present in the air mass and the surface temperature that the air passes over (Green 1979; Jones et al. 1990). Cooling usually results in the expansion of uplifted air caused by a decrease in atmospheric pressure as altitude is increased. Heat release by the process of condensation can result in additional energy that allows further rise of the air mass which can cause thunderstorms. Consequently, water vapour condenses into droplets only when small particles, such as dust, sea salt crystals, free floating bacteria, or smoke are present to serve as a catalyst. As a result the mass of droplets form clouds to which droplets move and clump together to form larger droplets until they become too heavy to remain suspended, consequently they fall as precipitation in the form of rain, snow or hail, gradually losing volume to evaporation as they descend to the surface of the Earth (Hunt 2004b).

Water evaporation from the oceans is significantly higher than precipitation. As a result there is a continuous transfer of freshwater from the oceans to the continents. Consequently water is captured in rivers, wetlands and lakes and gradually released back into the water cycle through evaporation or infiltrated below the surface into groundwater systems. Estimates of 45,000 km^3 have been reported of water returning annually to the oceans as river runoff and groundwater flows (Hunt 2004b). In contrast, Australia, because of the high evaporative demand climate and the flatness of the continent, very little surface water reaches the sea as river flow (Eamus et al. 2006b). The other rainfall pathway is taken up by roots of plants and evaporated through leaves through the process of evapo-transpiration.

Evapo-transpiration

The term evapo-transpiration refers to the combined processes of evaporation and transpiration where water infiltrates into the soil and migrates laterally towards a stream (interflow) or it may percolate downward to groundwater or water may return to the atmosphere through transpiration (Figure 2) (Drever 1997).

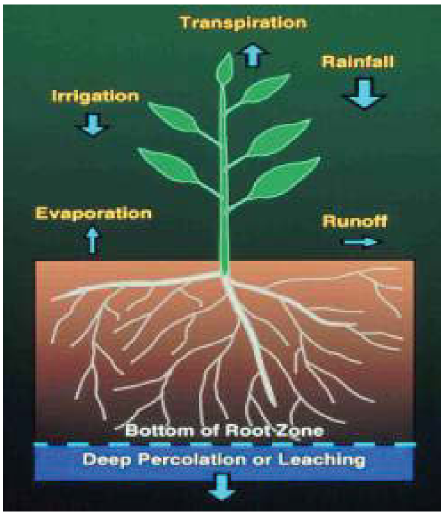


Figure 2: Cyclonic process of the evaporation and transpiration cycle (Source : *Soil water balance in irrigated cropping systems* 2007).

During the evapo-transpiration process water infiltrates and is absorbed into the roots by osmosis. Water travels from the roots, up the plant, to the leaves and is carried in tubes called xylem vessels as shown in Figure 3. Xylem vessels are microscopic capillary tubes that transport water. Xylem vessels are made of hollow, dead cells in plant stems and leaves grouped together with phloem vessels in vascular bundles (Figure 3) (Arms & Camp 1986; Eamus et al. 2006b).

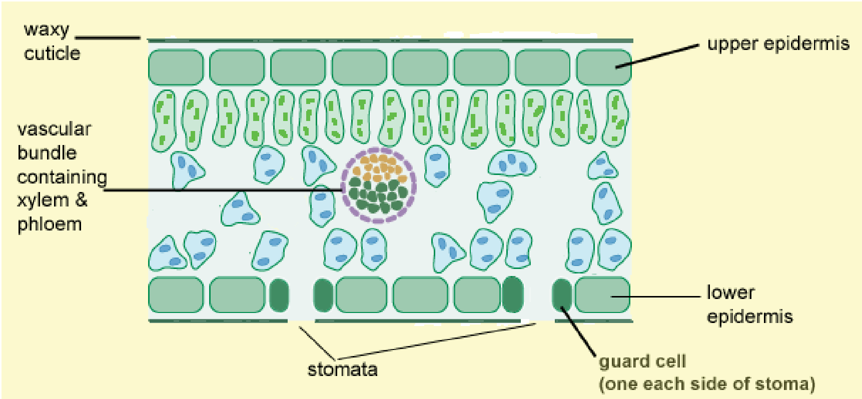


Figure 3: Evapo-transpiration processes of the plant physiology elements during evapo-transpiration (Adapted from *Schools biology green plants as organisms / water transports / transpiration* 2007).

The stomata (small guard openings) located on the underside of the leaves allows the plant to regulate water loss. As water reaches the leaves it evaporates and escapes through the stomata (Figure 3).

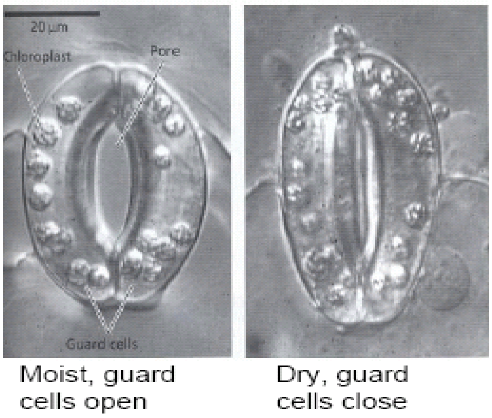


Figure 4: Stomata transpiration process shows the reaction of the stomata transpiration process during evapo-transpiration (Source: *Principles of Botany - Stomata transpiration* 2007).

Generally evapo-transpiration is the amount of evaporation from wet surfaces such as soil, wet leaf, plus transpiration through stomatal pores (Figure 4). As solar radiation increases during sunrise, leaf and air temperatures increase, the stomata in leaves open in response to the increase in light and in response to the decline in CO_2 concentration within the leaf. During the night stomata in the plants are closed as a result the transpiration rate is reduced at this time.

The water vapour concentration inside the stomatal cavity is greater than the atmosphere which allows the diffusion of water from the leaf. This diffusion of water is referred to as transpiration (Arms & Camp 1986; Eamus et al. 2006b).

Two thirds of rainfall that falls over land each year is the result of evapo-transpiration processes (Hunt 2004b). Evapo-transpiration requires high levels of solar energy to progress from liquid water in the cell walls to gaseous water in the atmosphere. Actual transpiration indices are poorly quantified after rainfall (Dube 2006) and variations in evaporation greatly influence the amount of water available. Uncertainties in measuring or estimating evaporation have a major effect on the reliability of water resource assessment.

The evapo-transpiration rate will vary depending on the vegetation type and density, the intensity, duration and frequency of precipitation that has been intercepted above ground (Eamus et al. 2006b). Catchment areas covered predominantly by vegetation are evapo-transpiration intensive which results in high porosity and infiltration rates. Water that remains in the soil upper substrate will provide moisture for terrestrial plants and water that infiltrates and continues downward will drain out of upper soils and accumulate as groundwater (Hunt 2004b). At this level, where the water reaches a saturation point is referred as the water table.

Interception

Interception applies to the processes that result in the temporary storage of precipitation by vegetation or by urbanised paved surfaces (i.e. roads, buildings, pavements). Intercepted precipitation can be either evaporated to the atmosphere or transmitted to the ground surface. The main components of interception by vegetation are ‘throughfall’, ‘stemflow’ and interception loss (Maidment 1992b). Throughfall occurs when water falls on vegetation and cascades as droplets (drips) through from the canopy and leaves directly to the soil surface. Stemflow occurs when water droplets fall on the leaves and run down the stems and trunks to the ground surface (Berner & Berner 1987; Wang et al. 2006). Water interception losses are greatest at the beginning of rainfall when precipitation retention by vegetation is at the greatest (Maidment 1992b).

Water losses are also strongly dependant on the scale of the plant canopy and water storage capacity. Such losses have positive correlations with CO_2 that lead to enhanced leaf production from carbon assimilation. The extent of carbon assimilation will be limited to the available carbon allocation which will influence and stimulate plant growth (Oliver & Oliver 1995).

Infiltration

The infiltration process occurs when precipitation soaks into the ground and infiltrates into the soil as soil water (Berner & Berner 1987) the portion of precipitation that is not evapotranspired or infiltrated, but flows instead overland until it reaches a natural stream, pond, wetland, lakes or oceans is referred to as surface runoff (Hunt 2004b).

Water that reaches the groundwater can be stored for very long periods and generally percolation to groundwater may occur in extreme events in which land surface may be flooded. Such events can be rare recharge pulses which may take decades or centuries to reach the water table (Falkenmark & Chapman 1989).

Water is transported by gravity and capillary action through the soil substrate and can transform to liquid from a gaseous state. The infiltration rate is dependant on the soil structure (i.e. soil particle size), texture, depth and the amount of water and organic material in the soil. When infiltration capacity is exceeded during rain saturation it will result in surface runoff. Water percolation occurs through the soil and rock until it reaches the groundwater zone and finally seeps by gravity to streams, lakes and ultimately back to the sea (Eamus et al. 2006a). This movement will continue to modify existing land formations and create new landforms as it progresses to the sea. Exceptions to the hydrodynamics of the water cycle are situations were soil absorption/saturation has exceeded the rate of infiltration and as a result surface run-off will eventually become stream flow or sheet flows (Eamus et al. 2006a). Other storage scenarios occur when water storage is locked in an ice state or in underground artesian formations restricting water movement back to the sea.

1.3 Global Water Masses and Distribution

Water is continually moving from one location to another or from one process to another as illustrated in the hydrological cycle (Figure 1). The total amount of water on the Earth's surface (hydrosphere) in the form of liquid, solid (ice) and gas (water vapour) amounts to 96.5 per cent saline and the 3.5 per cent freshwater (Table 1).

The global freshwater flux budget in precipitation, atmospheric transport, continental discharge, global evaporation and global water storage is poorly understood and measured. Studies are now only beginning to show precise measurements of global fresh water storage in global ice and groundwater. Accessible fresh water resources such as rivers, lakes, estuaries, and runoff and groundwater extraction are measured only in the most affluent regions of the world (Hildebrand 2005).

As a result satellite technologies are beginning to be used to measure and validate "on ground" measurements of water resources and make comparisons with analytical model analyses. Accurate quantitative data of global water resources are crucial in improving our knowledge to the impacts of human population increases and to the effects of climate change. These accumulative changes will increase evaporation and precipitation globally leading to the acceleration of the global water cycle (Hildebrand 2005; Huntington 2006).

Globally the planet is rich in water, with 75 per cent surface coverage (*World Day for Water 2000 - The Hydrological Cycle* 2000; Green 1979; Peavy, Rowe & Tchobanoglous 1985) but only 3 per cent is freshwater and suitable for human consumption, the remainder is saline (Nielsen 2005). Of the 3 per cent of freshwater 68.9 per cent is locked up in ice caps, glaciers and permanent snow in the Antarctic, the Artic and mountainous regions and 29.9 per cent exists as fresh groundwater (*World Day for Water 2000 - The Hydrological Cycle* 2000; Gleick 1996). The remainder, 1.2 per cent of available fresh water is derived from lakes, reservoirs and river systems (Table 1) (*World Day for Water 2000 - The Hydrological Cycle* 2000), further studies have shown that only 0.003 per cent of total water volume is usable by humans, most of which is replenished by the hydrological cycle (Mason 1996).

Table 1: The total volume and percentage of freshwater on Earth (Source: *World Day for Water 2000 - The Hydrological Cycle* 2000; Gleick 1996)

Environment	Volume ($1000km^3$)	Percent of Total Water	Percent of Fresh Water
Oceans, seas & Estuaries	1,338,000	96.5	-
Ice caps, Glaciers & Permanent Snow	24,064	1.74	68.7
Fresh Groundwater	10,530	0.76	30.1
Saline Groundwater	12,870	0.94	-
Soil Moisture	16.5	0.001	0.05
Ground Ice & Permafrost	300	0.022	0.86
Fresh Lakes	91.0	0.007	0.26
Saline Lakes	85.4	0.006	-
Atmosphere	12.9	0.001	0.04
Wetlands	11.47	0.0008	0.03
Rivers	2.12	0.0002	0.006
Biosphere	1.12	0.0001	0.003
Total	**1,385,985**	**100**	**100**

Water in the Atmosphere

The atmosphere contains a relatively small amount of water in the form of rain clouds. The total amount of water vapour in the atmosphere represents only 0.001 per cent of the total water on the earth (*World Day for Water 2000 - The Hydrological Cycle* 2000; Gleick 1996). The volume of water in the atmosphere ranges from 13,000km^3 to 15,000km^3 at any point in time (*World Day for Water 2000 - The Hydrological Cycle* 2000; Gleick 1996; Hunt 2004b; Maidment 1992b).

The atmosphere recycles its entire water content thirty three times each year which results in a mean global residence time from eight to eleven days (Hunt 2004b; Maidment 1992b). The amount of water vapour in the atmosphere varies due to warm air holding more water than cold air, as a result the average annual vapour content decreases from 50mm from the equatorial regions to less than 5mm over the polar regions (Hunt 2004b). This concentration of water is an important component of supporting life on Earth in that it provides two thirds of the total amount of greenhouse gases that warm the planet by trapping heat in the atmosphere. The absence of these gases would decrease the mean surface temperature, as a result the planet would freeze and liquid water would be absent from the surface of the Earth.

The concentration of water vapour can be expressed as absolute humidity or water vapour pressure which represents about 2 per cent of the atmospheric pressure at the earth's surface. As air becomes supersaturated, and water condenses, the temperature decreases with height in the atmosphere at an average rate of -6.5° C/ km. Air in the stratosphere contains a constant amount of water vapour because air travelling at this height has already lost most of its moisture by condensation in the troposphere. This process also acts as a trap that prevents loss of water from the earth to space (Berner & Berner 1987).

Water on the Earth's Surface

The average annual rainfall on the surface of the continents is approximately 746mm (Hunt 2004b) (Table 2). The distribution and storage of water is influenced by seasonal temperature variations. This is typical of how water flows globally into the oceans by the detention of snow in the northern hemisphere. The snow cover in North America Europe and northern Asia, receive maximum coverage in March and April which depletes at the end of August. This delay provides the oceans with their maximum storage around October. Further, the inflow allocation of water from precipitation and evaporation from the continents produces a surplus in the Indian and Atlantic Oceans and a deficit in the Pacific and Artic Oceans (Hunt 2004b). As a result there is a continuous transfer or turnover of water from the Indian and Atlantic Oceans to the Pacific and Arctic Oceans as shown in Table 2 and 3.

Table 2: Annual water balance of continents (Source: Berner & Berner 1987; Hunt 2004b; Meybeck & Helmer 1998a).

Continent	Area	Precipitation		Evaporation		Discharge	
	(10^3 km^2)	(10^3km^3)	mm	(10^3km^3)	mm	(10^3km^3)	mm
Europe	10	6.6	657	3.8	375	2.8	282
Asia	44.1	30.7	696	18.5	420	12.2	276
Africa	29.8	20.7	696	17.3	582	3.4	114
Australia	8.9	7.1	803	4.7	534	2.4	296
North America	24.1	15.6	645	9.7	403	5.9	242
South America	17.9	28.0	1564	16.9	946	11.1	618
Antarctica	14.1	2.4	170	0.4	28	2.0	142
Total	148.9	111	746	71.3	480	39.8	266

Table 3: Annual water balance of oceans (Source: Berner & Berner 1987; Hunt 2004b).

Oceans	Area	Precipitation		Evaporation		Discharge	
	(10^3 km^2)	(10^3km^3)	mm	(10^3km^3)	mm	(10^3km^3)	mm
Arctic	8.5	0.8	97	0.4	53	0.4	44
Atlantic	98.0	74.6	761	111.1	1133	-36.5	-372
Indian	77.7	81	1043	11.5	1294	-195	-251
Pacific	176.9	228.5	1292	212.6	1202	15.9	90
Total	361.1	385	3193	224.7	3682	-215	-489

Tables 2 and 3 depict the global annual water balance of continents and oceans. The global annual water balance will vary as water exchanges take place between the oceans, land and the atmosphere (*World Day for Water 2000 - The Hydrological Cycle* 2000). Data shown in Tables 1, 2 and 3 can be viewed as generic. Evaporation and precipitation generally do not balance (Berner & Berner 1987). On land or continents and oceans, the precipitation rates exceed the evaporation rates. The difference in each case comprises water transported from oceans to the continents as atmospheric water vapour, river runoff and groundwater recharge or discharge to the oceans.

1.4 Water Cycle Strategic Approaches

The aim herein is to assess water cycle management strategies in a local government context. The emphasis is on recognising the water cycle as a holistic system that involves the assessment of water, the management of human induced impacts and conservation of water resources.

Water resource management strategies are necessary tools for planning and initiating actions that will achieve sustainable outcomes in response to development pressure. As discussed earlier ecological research has focused on individual components of the hydrological cycle, rather than the whole water cycle process (Ashton et al. 2005). A balanced holistic approach needs to be developed to manage the urban environment in harmony with the environmental demands of the water cycle.

Current environmental management approaches have adopted a three pronged approach, known as the “triple bottom line” (TBL) involving environmental, social and economic considerations. This management approach assumes that the balance of TBL can be altered to compensate for the degradation of one element in response to the improvement of other/s TBL considerations to maintain sustainable management (Kettle 2005).

1.4.1 Triple Bottom Line

The term ‘triple-bottom-line’ (TBL) was introduced by Elkington (2002) and has consequently been adopted by local governments irrespective of the benefits and outcomes (*Water for today and tomorrow - An Integrated Water Strategy for Brisbane* 2005). Traditionally, the term “bottom line” metaphor refers to corporations profit used in the earnings statement which is part of standard accounting practice in assessing the company’s financial performance (Elkington 2002).

The “triple-bottom-line” concept provides performance indicators of an organisation to achieve a balanced approach in sustainable management (Elkington 2002). Economic considerations may include long term sustainability of cost, product demand, services and profit and loss margins, and research to determine bench marking for best practice methods.

The environmental ‘bottom line’ is characterised as natural capital which maintains ecosystem integrity and protection of biodiversity, remediation of natural environments and the sustainable use of natural resources.

The social 'bottom line' is identified as social capital, it embraces social community, ethical and cultural values. It encourages stakeholder involvement to work together for common purposes and highlights a broader outlook beyond pollution control (Elkington 2002). The fact remains in meeting our current needs the desire by industry for natural resources is overwhelmingly destroying the ability of future generations to meet their needs (Elkington 2002).

Even if all organisations within the commercial sector were to achieve zero emissions, the Earth would still be stressed beyond its carrying capacity due to depleted resources in farmland, fisheries and forest. These issues are not simply economic and environmental, but have social and political implications that are at the root of the crisis. For example, Elkington (2002) feels that corporations, not governments, are the only organisations with the resources, the technology, the global reach and ultimately, the motivation to achieve sustainability. He further adds that, new industries and technologies are emerging to restore environmental sustainability through reuse of water resources, energy production without carbon emissions, solar energy, reuse of waste materials and the conservation of natural resources.

The triple bottom line strategic framework can align organisational visions, goals and outcomes, and provide clear and defined communication channels for stakeholder integration. It encourages participation on issues of social relevance were transparency and accountability is crucial. The strategic process can introduce, integrate, utilise and share technical and non-technical data to manage qualitative and quantitative information. The triple bottom line assessment can assist catchment managers to make systematic, informed, holistic, transparent, multidisciplinary, defendable, socially acceptable, cost effective and ecologically sustainable decisions (Taylor & Fletcher 2005).

Critically, it is questionable whether the triple bottom line process can produce proven environmental benefits in water cycle management. The concept is driven by a cost benefit analysis where the main focus is financial gain, hence the bottom line "metaphor". The application of triple bottom line in a local environmental context would invariably duplicate a lot of the triple bottom line criteria especially in the field of environmental assessment (e.g. impact assessment, environmental impact statements, review of environmental factors, review of environmental effects) (Gilpin 1996).

Further, triple bottom line reporting is resource intensive, complex and unclear as to its performance indicators for achieving sustainable outcomes within local government.

Different strategic approaches such as triple bottom line can give markedly different outcomes. To some extent this is dependant on what elements are considered important and how these strategies are applied, but it may also be due to inherent differences and biases towards economic considerations (Beatty, O'Brien & Stuart 2005).

Irrespective of these criticisms the 'triple-bottom-line' concept has been adopted by local government nationally in Australia as an environmental framework to promote the sustainable use of water resources. As a result and for this reason the concept has been applied to this project as depicted in Figure 5 for encompassing social, environmental and economic values within the water cycle management strategy.

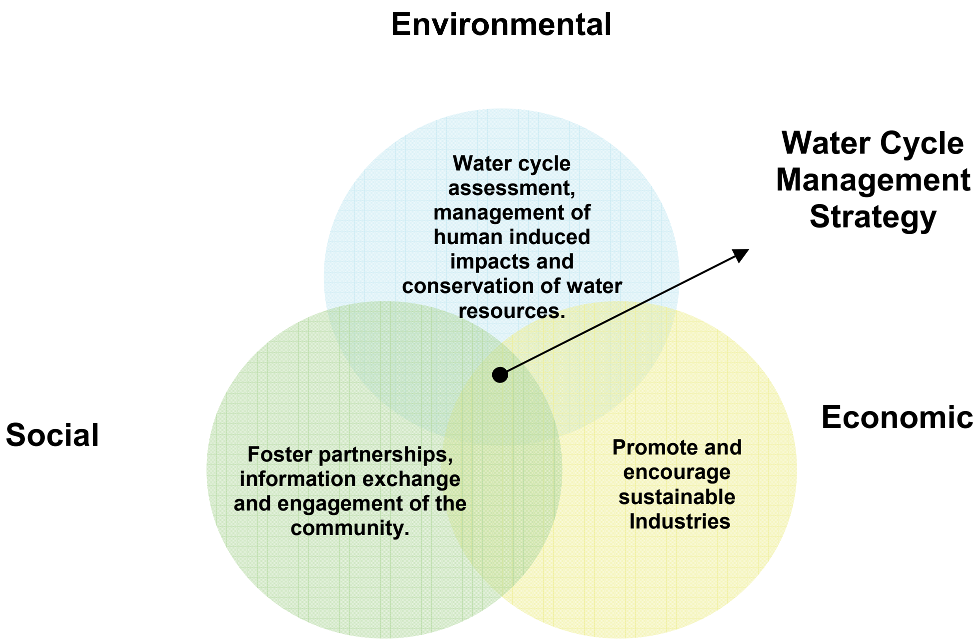


Figure 5: Triple bottom line integration with the Water Cycle Management Strategy.

1.4.2 Water Cycle Management Strategies

In general water cycle management strategies should combine prediction, acknowledgment of uncertainty and be adaptable and flexible to accommodate science innovation and advancement. The desired strategic actions should respond to performance and quality monitoring as trends become more apparent and the knowledge base expands. However, before management can determine what strategies are best suited for a desired outcome in the long term, authorities and community stakeholders must have a collective vision leading to goals that will achieve sustainability of water resources, supported by an understanding of the effects of human induced impact on the water cycle.

Water cycle management in the United States is very parochial and politically focused with an emphasis on global scientific assessment. The U.S. Global Change Research Program (USCGCRP) placed a high priority on research into the global water cycle (*United States Global Change Research Program* 2001).

The specific requirements outlined in the “Plan for a New Science Initiative on the Global Water Cycle" has resulted in the Water Cycle Study Group which report to the US Global Change Research Program. The Plan describe the rationale for an enhanced scientific research effort on the global water cycle over the next decade and poses key questions regarding water-cycle variability, prediction, and links with ecosystem processes.

This approach included three elements of the water cycle:

- improved observations, including innovative measurements using new technologies and networks for coordinated observations;
- a set of coordinated field, remote-sensing, and modelling experiments; and
- regional climate models to provide a means of linking atmospheric, land surface and subsurface processes (*United States Global Change Research Program* 2001).

This program is resource intensive and highly science orientated with links to NASA satellite sensor remote imagery technologies that assess global water cycle variability with an emphasis on North America and the United States National Science Foundation.

The United States National Science Foundation (USNSF) promoted and awarded research grants in science and water cycle research. The aim of the water cycle project determine how natural fluctuations and anthropogenic elements may have impacted the water cycle in regards to mass and energy transfer across the interfaces between land-atmosphere and land-ocean. The research program (in progress) has broad implications and was considered very technical. It specifically focused on understanding the function of the water cycle as a transport agent for mass and energy that include pathways and fluxes of water, solids, causes of water cycle flux variability, predictions and linkages of fluxes (Dumenil-Gates, James & Batiza 2004). The scope and terms of reference and the objectives of this program may be in part relevant to water cycle management in Australia in view of the similarities in climate, spatial and temporal characteristics. The results of this work, when completed, would be very useful to better understand water management on an international scale.

The Water Framework Directive (WFD) of the European Union introduced a strategic legislative framework that provided a holistic and integrated approach to water management and conservation. The strategic framework focused on the protection of aquatic environments by setting objectives to ensure all waters achieved a “good status” by initiating steps to prevent water quality deterioration. The distinct difference from previous approaches from the European Union was that this approach included pollution control by taking into account the quantitative use of water through water management plans. Water was given a legal identity and status and was defined as a natural resource throughout the European Union, flowing from place to place. It further obligated users to comply with and to have equal access to manage water resources. The rationale behind the WFD focused on water pricing promoting more sustainable use of water resources (Andersson 2007).

The general feeling was that competing needs between different countries may not provide a fair and sustainable allocation of water resources between neighbouring countries within the WFD. This concern was based on the premise that unclear ownership water rights have been difficult to regulate in a sustainable way throughout the European Union.

South Africa generally has similar seasonality, climate and vegetation structure to Australia, more importantly South Africa has been very pro-active in the assessment and management of its natural resources to achieve sustainable management (Eamus et al. 2006b).

The South African Water Research Commission (SAWRC) is dedicated to the management of sustainable water research in South Africa. The SAWRC is a research and management authority that focuses on five key strategic areas that provide a multidisciplinary research approach for solving issues related to national needs in water resources (Liphadzi 2006).

The five strategic areas included:

1. water resource management - generating a research base, that develops skills to ensure water resources are protected, utilised, developed and conserved to achieve environmental, social and economic sustainability;
2. water-linked ecosystems - provides knowledge to sustain the function and services of aquatic ecosystems;
3. water use and waste management - provides the research required for efficient water use, the prevention of pollution and the development of treatment technologies for water and wastewater;
4. water utilisation in agriculture - provides the needs of current and future agriculture water demand, supporting water efficient technologies; and
5. water centred knowledge - provides information sharing and communication and public understanding of the science.

The South African water cycle strategy involved a scientific approach with a nationalistic reach that incorporated management with science whilst integrating environmental, economic and social needs. Programs such as understanding the hydrological cycle, techniques for evaporation monitoring and rainfall mapping were relevant and essential to the assessment and management of the water cycle. The SAWRC placed a high emphasis on developing a scientific understanding of the hydrological cycle in order to promote systematic assessment and management. It further highlighted the need for supporting research and developing technologies that would provide scientific information on the water cycle, soil-water balance, environmental flow dynamics and the relationships to atmospheric processes that would result in good long term and sustainable management practice.

The South African approach may be considered too technical, resource intensive and financially demanding for local government. The high level of stakeholder involvement and the complexities of integrating and coordinating actions may result in losing direction in relation to the goals and performance of the water cycle program.

In Australia, water cycle management strategies have been mainly focused on water demand management in view of the prolonged drought conditions.

The Victorian Government's sustainable water management strategy has been directed at securing water supplies for urban users. The Strategy was primarily a plan to secure water supplies for the central region of Melbourne. It forecasted the need for an extra 66GL of water for the region by 2015, it also aimed at providing opportunities for river systems to regain environmental flows and create area reserves for major aquifers without comprising supplies to urban users.

The Strategy focuses on the central region of Melbourne with an action plan to 2055. The goals were directed at river health, understanding the implications of climate change in relation to low rainfall, water consumption and shortfalls in water supplies in view of current drought conditions. The key actions included water conservation and efficiency, recycling at the local level, augmentation works to increase and secure future water supplies to Melbourne by upgrading water systems and promoting recycling.

Ecological considerations focused on the protection of rivers and aquifers for there aesthetic and social value and purifying water by biological processes. Reserves (i.e. recreational parks and protected natural open spaces) have been designated for each major river in the central region to achieve these actions. A major emphasis of the Strategy was the implementation of adaptive management which provided the impetus to react to environmental change with minimal scope for long term planning (*Sustainable Water Strategy Central Region Action to 2055* 2006). It is however, unclear how the objectives would be achieved in relation to social and ecological targets or how the dedication of catchment reserves would be accomplished within the Strategy.

The City of Melbourne approach to total water management has seen the introduction of the "*Total Watermark"* total water management strategy (*Total Watermark* 2004). The principles which underline the strategy included the preservation of the natural environment, water consumption reduction, the promotion of reuse and recycling of wastewater and the prevention of groundwater pollution. The Strategy was based on water conservation, stormwater management, wastewater management and groundwater management.

The Strategy targeted a 40 per cent reduction of water consumption per person with an overall 12 per cent saving in water consumption by 2020. The Strategy further promoted reuse and recycling of wastewater as a renewable resource and considered the importance of groundwater as an integral part of the water cycle. It emphasised pollution prevention and impacts to groundwater and highlighted the integration of all components of the hydrological cycle within urban areas (i.e. surface water, soil inter flow, groundwater, water supply and recycled wastewater) that supported social, economic and environmental benefits (*Total Watermark* 2004). The Strategy had favourable elements in relation to water conservation, reuse and demand which seemed to be the main thrust of the Strategy. Ecological considerations were minimal in regards to the management of ecosystem health (i.e. environmental flows, aquatic processes, riparian zones and water quality).

The Brisbane City Council has produced a total water cycle management strategy (*Water for Today and Tomorrow*) (*Water for today and tomorrow - An Integrated Water Strategy for Brisbane* 2005). The Strategy details a framework of goals to manage the water cycle for the city as well as the surrounding rural regions. The Strategy recognises two main elements, wastewater treatment and stormwater management. It focuses on poor land management as the main contributor to environmental degradation, advocating the “Brisbane lifestyle”, and encourages water resources within the LGA to be managed holistically to deliver social, ecological and economic sustainability.

The objectives included community values of water, building strong partnerships, managing water to meet our social obligations, creating healthy waterways, providing sustainable water services and minimising the impact of flooding in view of population growth, climate change, water supply with demand, waterway health, flood management and the economy.

This strategy is a broad document with minimal appreciation of the water cycle and its interaction within the environment. It does not propose any understanding of the water cycle within the built environment and does not prescribe any priorities for the actions or performance indicators of the outcomes.

In NSW, in October 2004, dam levels fell to 42.6 per cent in the Sydney metropolitan area. In response to these concerns the NSW Government implemented water restrictions and water demand strategies such as the 2004 Metropolitan Water Plan to maintain water supplies for Sydney (*The Metropolitan Water Plan 2004 - A NSW Government Initiative* 2004). The Plan identified factors that are a major influence on water supplies for the Sydney metropolitan area, these included population growth, drought, climate change and river health. In response, the Plan actioned accessing deep water from Avon and Warragamba dams, increasing water supply transfers from Shoalhaven and field assessments to examining the viability of extracting groundwater for potable use and the installation of a desalination plant. Programs such as BASIX (Building Sustainability Index) were included to reduce water consumption in new residential buildings with targets of 40 per cent being projected and regional plans were proposed to protect the integrity of Sydney's catchments (*The Metropolitan Water Plan 2004 - A NSW Government Initiative* 2004).

The western region of Sydney has been highlighted for the use of recycled and reclaimed water for residential, industrial, agriculture and environmental purposes. To support the program, the Plan proposed to streamline the regulatory system (i.e. recycled and reclaimed guidelines, standards) for water recycling, although it is unclear how or who will take on this responsibility. The Plan further endorsed the reduction of water demand by encouraging the application of water efficient fixtures by regulative requirements, subsidies and water mains infrastructure leakage reduction.

Environmental considerations focused on the effects of environmental flows caused by the damming of freshwater. As a result, the Plan detailed environmental flow releases were made by installing outlets at the major dams and weirs. Flows will be monitored to gauge the effectiveness of the Plan.

The findings of a study commission by the Government to review the effectiveness of the 2006 Metropolitan Water Plan (*2006 Metropolitan Water Plan - Water for Life* 2006) recommended: newly identified groundwater reserves would offer good prospects; increasing recycling will offer significant additional potable water supplies and investment in desalination technologies to be used when needed to reduce demand and for water restrictions to remain in force until 2015 (White & Campbell 2006). The Government has since announced in June, 2007 that water restrictions will remain permanently.

The Sydney Metropolitan Water Plan is a reactive initiative and is highly political promoting the Government in a positive light. The Plan is purely a water demand and supply strategy linking existing water conservation initiatives. It does not provide any major reforms in regards to water re-use or recycle of water or long term planning. Water cycle management is referred once in the document as a token term in relation to water infrastructure as a key factor within the Plan. It is however, unclear to what strategic capacity water cycle management will be applied within the overall water infrastructure. The exploitation of groundwater resources is highlighted within the Plan as an alternative to desalination (White & Campbell 2006). This aspect raises environmental concerns to the sustainability of groundwater resources and to the Sydney basin water cycle regime.

To manage water resources sustainably requires 10 to 100 years projected planning incorporating a water balance demand approach incorporating population growth, environment, engineering and economic disciplines with the foresight to develop and establish long term strategies with clear timeframes. Such strategies should consider climate variability, based on factual science and be removed from political bias. For example, climate change is used consistently (without factual science) as being responsible for unpredictable droughts within the Plan. This aspect only provides the State Government an escape clause to screen management incompetence for managing water resources efficiently.

Reactive management of water resources invariability present little understanding of the long term environmental consequences of water resources and may not meet the demands of future generations. (*The Metropolitan Water Plan 2004 - A NSW Government Initiative* 2004). It could be assumed that should dams become full most of the water plan initiatives will be downgraded , diluted or totally abandoned until the next water demand crisis emerges, by then the water demand-supply balance could change substantially as a result of population growth.

The Sydney Regional Coastal Management Strategy - Water Cycle Management - (*Sydney Regional Coastal Management Strategy* 1998) was drafted in 1998 , the Strategy targets the protection and conservation of the Sydney terrestrial and marine coastal environment. The Strategy outlines management programs: water cycle management; nature conservation; public access; role of government; climate change and cultural heritage practices in social, economic and sustainable coastal planning. The framework is directed at local governments and is aimed at achieving Ecological

Sustainable Development (ESD) for the coastal region. The Strategy recognised that the Sydney coastal region is under intense pressure from urbanisation. It emphasised that a single management strategy based on ESD principles should be adopted by all stakeholders to reconcile all competing interests with a common goal of achieving integrated sustainable management. The goal is to *"improve the total quality of life both now and in the future that maintains the ecological processes on which life depends*". The core objectives include: enhancing community well-being for future generations; to provide equity within and between generations; to protect biological diversity and maintain ecological processes and life support systems.

The Strategy is heavily dependant on coastal regional issues ranging from poor water quality to insufficient water recycling policies, permeability of catchments, community understanding, groundwater appreciation, monitoring of point and diffuse pollution, impacts of sewerage, retention devices and loss of natural drainage. The strategy has a holistic approach to water cycle management, however it focuses primarily on water quality in relation to coastal development with little appreciation of water cycle processes in regards to precipitation, evaporation, ecological foot prints population density and catchment assessment.

The NSW Department of Energy, Utilities and Sustainability (DEUS) introduced Integrated Water Cycle Management (IWCM) in May 2004 (*Integrated Water Cycle Management* 2004). The IWCM concept is directed at regional Councils who own and manage local water utilities. The purpose of the strategy is to encourage regional Councils to formally manage their water systems by integrating water supply, sewerage and stormwater, so that water is used optimally within a catchment resource. The strategic process involves integrating planning and management of water supply, sewerage and stormwater functions to ensure that water is used primarily for urban development (*Integrated Water Cycle Management* 2006). The assumption is that integrated holistic systems rely less on natural water resources because the emphasis is directed at demand management, effluent reuse and stormwater use.

An important element of IWCM is the emphasis on communication and information sharing with other water users and managers e.g. Catchment Management Authorities in achieving integration with planning and implementing the strategy.

The process adopts five principles:

1. consideration of water resources planning;
2. sustainability of resources;
3. needs of water users;
4. integration of natural processes; and
5. integrating natural resources and management (*Integrated Water Cycle Management* 2004).

The IWCM promotes rainwater tanks, dual reticulation, stormwater harvesting and effluent management. These approaches also encourage "end use" water efficiency such as low flow showerheads and flow restrictors in domestic applications.

The IWCM process relies heavily on balancing water requirements with available resources within regional catchments. IWCM does have broad deficiencies in that it does not consider the demands or values of ecological communities and assumes that fresh water whether its rain, surface or ground water is for urban use with little regard to the demands of the natural environment. The main focus is directed at the demand for freshwater resources for residential and urban sectors. The ecological consequences are considered a minor consideration within the utilities industry, although some IWCM studies have included ecological systems in relation to water quality (algal blooms, nutrients and deforestation) and environmental audits examining environmental degradation in relation to deforestation (*Kyogle Integrated Water Cycle Management Strategy - Part 1: Concept Study* 2003).

Management approaches such as integrated water cycle management focus on optimising water resource benefits at a localised scale for water supply, sewerage and stormwater (*Integrated Water Cycle Management* 2004). However, it is questionable whether any ecological benefits are derived from this approach. This is not to suggest that conservation technologies such as rainwater tanks, low flow showerheads are less worthy of consideration within the water cycle management process. Rather, the approach of integrated water cycle management should be expanded to encompass the broader ecological landscape within the water cycle.

The IWCM management plan does have social risk which stems from making assumptions on human behaviour and how communities react to trends and changes. As a result meaningful engagement of communities needs to be recognised as a significant element of the integrated water cycle management process. Without a firm understanding of how human impacts interact with strategies and management processes of the water cycle, authorities and organisations will find it difficult to understand the demands, needs, views and expectations of communities (Pryor, Azar & Morris 2005). Case studies have shown that integrated water cycle management can minimise the impact on the water cycle from urban development. The benefits, however are moderate and concerns were raised as to the integration of water supply, stormwater and wastewater and to the performance assessment of integrated water cycle management (Mitchell 2006).

Further, water cycle management strategies need to have a balanced approach to triple bottom line. The integrated water cycle management approach is predominately driven by the economics of the locality. Social and environmental factors are incorporated within the framework as a token, and in reality they are a minor consideration, making the process a financial bottom line approach.

In adopting IWCM, Eurobodalla Shire Council was heavily influenced by the triple bottom line methodology. The approach had little recognition of the water cycle as a holistic system i.e. rainfall, surface water, landuse and groundwater. Economic benefits from water reuse programs were the main considerations (*Kyogle Integrated Water Cycle Management Strategy - Part 1: Concept Study* 2003; Iyadurai, Contos & Bailey 2003) .

The Lake Macquarie City Council, located to the north of Sydney in NSW, produced Water Cycle Management Guidelines which were adopted in January 2006 (Donovan, Cameron & Coombes 2002). The aim of these guidelines was to support ecological development through "water sensitive urban design". The guidelines cover topics such as water cycle management control measures for the design and planning of urban development and water cycle impact minimisation (i.e. flooding, accelerated sedimentation, poor water quality and degraded aquatic systems).

The objectives of the guidelines included reducing flood risk and erosion in urban areas and waterways, improving water quality in stream and groundwater, efficient use of water resources, protecting and restoring aquatic and riparian ecosystems and habitats and protecting recreational values and landscapes of streams. The Water Cycle Management guidelines proposed a decentralised approach that was more attuned with natural hydrological and ecological processes. It proposed a treatment train approach for managing urban impacts with an emphasis on re-use, infiltration, protection of native vegetation and the minimisation of site disturbance and conservation of habitat.

The Guidelines did have an advantage in that they were specifically designed to support local government development control plans in building and subdivision design and exempt development. The Guidelines incorporated specific assessment criteria in relation to site characteristics such as soil type, slope, water table, rainfall, scale and density of the development. This approach focused on development control with minimal appreciation on water cycle management in regards on how the water cycle interacts with urban design and the assessment of land use constraints in relation to water cycle balance.

Gosford City Council adopted a Water Cycle Management Development Control Plan (DCP) in 2003 (*Development Control Plan No.165 - Water Cycle Management* 2003). The purpose of the DCP was to use water efficiently in new developments and to minimise the impact on the natural water cycle. The objectives included reduction of runoff, demand management, improvement of water quality, and to reduce the cost of providing and maintaining water infrastructure. The document was limited in scope and is presented as a fact sheet. It highlighted two areas, the efficient use of water fixtures and rainwater tanks.

Kogarah Council, situated in the Sydney metropolitan area, developed a Total Water Cycle Management strategy (Chanan & Woods 2005) based on a case study for the Beverly Park Catchment (*Total Water Cycle Management Framework - A Case Study on Beverly Park Catchment , Kogarah* 2004). In this case study, planning and end-use model scenarios (i.e. water efficient devices) were evaluated for their cumulative impact on reducing potable water, dry weather discharge to sewers and reducing run-off.

This management approach relied on managing water demand and supply with an emphasis on water reuse and wastewater reclamation. The approach also attempted to improve water use efficiency by recognising stormwater and wastewater as a resource. Some of the projected benefits included the reduction of outfall outputs from sewerage treatment plants and the development of end-use modelling and monitoring of water use. The Beverley Park case study reclaims 0.4 ML of sewage daily which is treated and reused for irrigation at the Beverly Park Golf Club and other parks within the Kogarah LGA.

This strategic approach was a water treatment/ reuse and end-use strategy and did not encapsulate the total water cycle. The strategy was costly ($3m) had limited scope and did not recognise the ecological impacts, the demands of ecological systems or considered the water balance of the water cycle to determine sustainability (i.e. precipitation, evaporation, runoff, environmental flows and groundwater).

The literature reviewed has shown the significance and the complexities of how the water cycle interacts with the natural environment. Water cycle management strategies assessed, have shown how effective water cycle strategic approaches have been in terms of integrating the elements of the water cycle to achieve sustainable outcomes. The aim and objectives formulated herewith are the result of the findings of the literature review for managing the water cycle.

1.5 Aim

To develop a management template that can be applied to small or large scale applications for achieving sustainable water cycle outcomes for local government.

1.6 Objectives

The objectives are:

- to define the water cycle and its interactions (Chapter 1.0 -1.3);
- to review literature on water cycle management strategic approaches being applied by authorities and local governments (Chapter 1.4);
- to apply a case study examining the environmental pressures and management responses from a local government perspective that led to the establishment of a water cycle management strategy (Chapter 2);
- to develop a new and effective generic water cycle management strategic decision framework that will integrate science, management and stakeholders to improve the assessment, management and conservation of the water cycle (Chapter 3) ; and
- to provide concluding recommendations for the implementation of water cycle management strategies for local governments (Chapter 4).

1.7 Methodology

The methodology for developing a generic Water Cycle Management Strategy template adopted a multi faceted approach that brought together observations and judgements (Dale & English 1999) and values involving scientific assessment, management of human induced impacts and conservation of water resources and stakeholder integration.

In order to develop a methodology framework, it is important to understand, not only the elements required to develop the framework, but also the forces that drive the main strategic elements (Smith, Sant & Thom 2001) . Information sources were derived from reviewing and critiquing existing scientific and management approaches. In addition, a case study that had effectively integrated past and current science and management practices in water cycle management was also assessed.

Figure 6 illustrates the process for producing the water cycle management strategy.

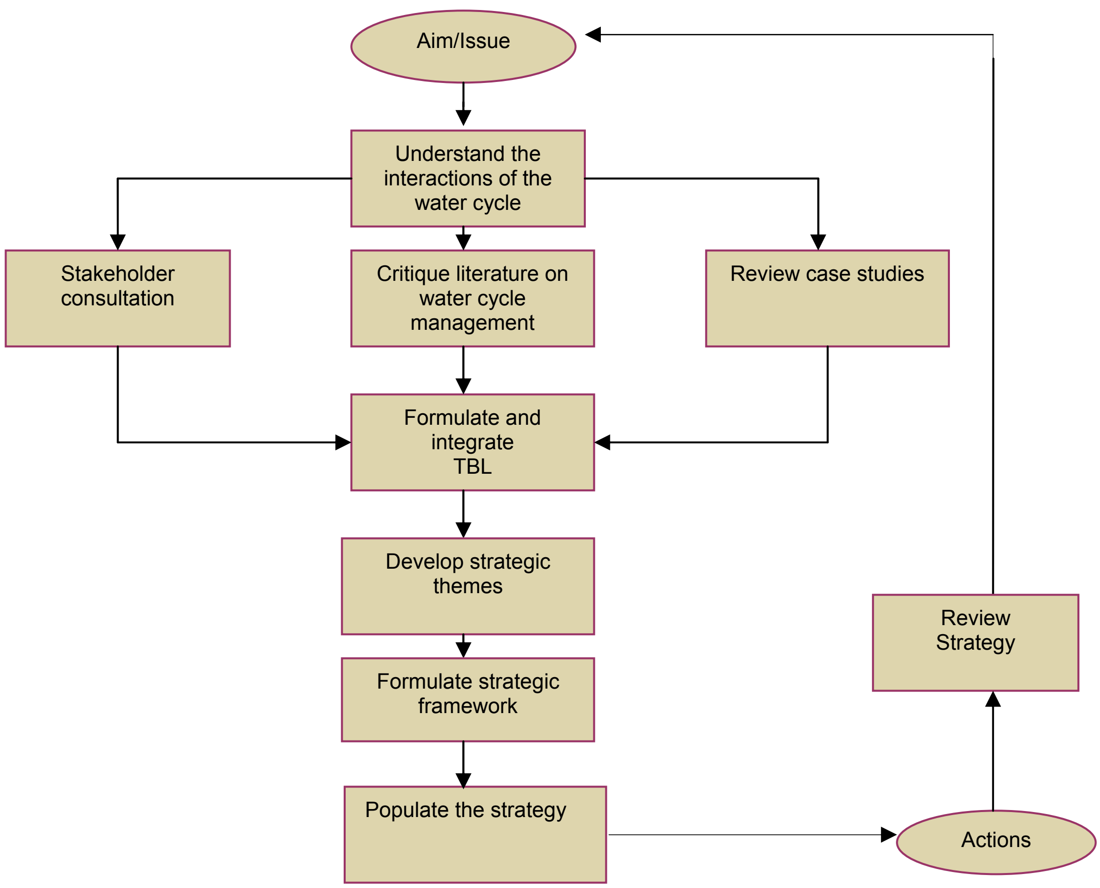


Figure 6: The methodology process of the water cycle management strategy.

The following tasks outlined the process.

Identify the issue

This task identifies the aim/issue to be addressed. As a result the project aspires to develop a water cycle management strategic framework, which can be applied by small or large scale Local Governments to achieve sustainable outcomes.

Understand the water cycle and its interactions

This stage defines the water cycle and it's interactions within the natural and urban environment. This task provides background research and set the scene in understanding the processes of the water cycle (i.e. precipitation, evapo-transpiration, infiltration and interception). It further reviews the significance of global water distribution, the shortage of fresh water as a global resource and highlights the importance of efficient water management practices.

Critique literature on water cycle management strategies

This stage reviews and critiques literature on water cycle management approaches and evaluates a local government case study in detail. This task provides information on the current strategic approaches applied nationally and internationally. It also examines specific water cycle management programs in the local government context. Stakeholder consultations were undertaken internally, at seminars and conferences and from telephone and email communications to source information on current water cycle management applications.

Integrated 'triple bottom line' (TBL) values

This task assesses the significance of the 'triple bottom line' concept and its relevance to water cycle management. As a consequence, social, environmental and economic values would be integrated within the Strategy to provide an equal appreciation of social and economic issues within the strategic framework.

Development of strategic themes

This task involves developing strategic themes that represents the water cycle as a holistic system. It recognises and integrates triple bottom line values, scientific assessment, management of anthropogenic impacts and conservation practices as significant themes in managing the water cycle. Based on the findings of the literature, three strategic themes were formulated to drive the strategy. These include the assessment of the water cycle, management of human induced impacts and the conservation of water resources.

Development of strategic framework

This task develops the strategic framework based on literature and experience in project management. The task outlines the format of the goals, objectives, actions, time priorities and projects costs. The task also develops the administrative and management framework, identifies stakeholders and develops key performance indicators to review the performance of the Strategy.

Populate the Strategy

This task involves populating the three strategic themes with goals, objectives and actions. The task also entails researching and planning management programs to achieve the desired outcomes. The strategic actions includes programs in water balance and water quality assessment, stream flow, ecosystem health, catchment modelling, regulatory planning, water sensitive urban design, water treatment, groundwater management, climate change, water consumption and conservation management and community information exchange /education.

Review and reassessment

The final task involves the review of the strategy by industry, academia and stakeholders to gauge the effectiveness of the project for achieving the overall aims.

2.0 Case study: "A Sustainable Total Water Cycle Management Strategy in Hornsby Shire Council”.

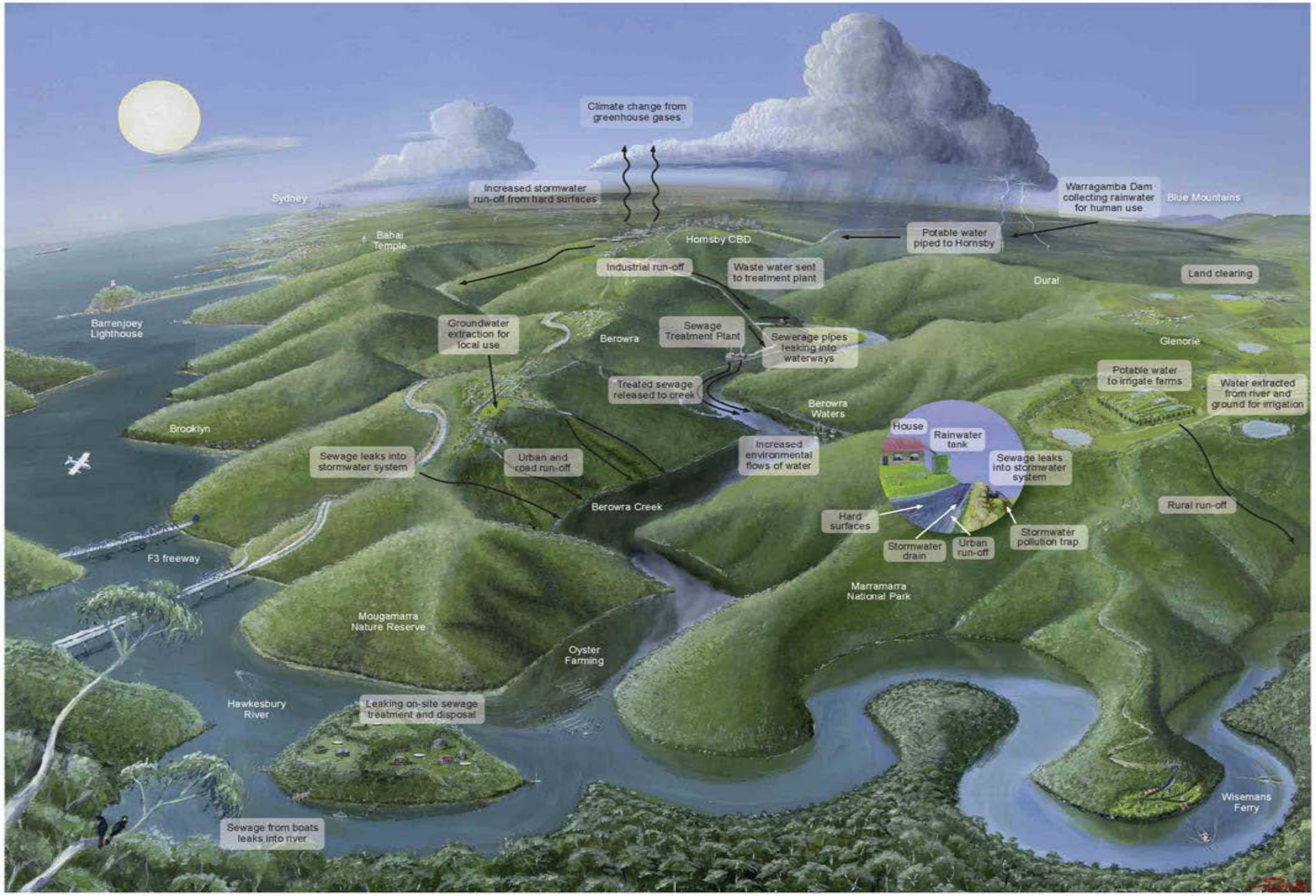
2.1 Background

This case study examines the Hornsby Shire Council’s approach to environmental pressures and management responses from a local government perspective that led to the establishment of a Water Cycle Management Strategy. A schematic depicting the water cycle in relation to anthropogenic impacts and the Berowra Creek Estuary is shown in Figure 7. Hornsby Shire Council is acknowledged as progressive and innovative in water cycle management. Water cycle management strategies developed by Edgerton, et al (2005) for Hornsby Shire Council and together with other literature have provided an impetus for this research.

The case study reviews how Hornsby Shire Council developed an environmental strategic rationale integrating science and management initiatives to restore the ecological health of the Shire’s waterways (McPherson & Gunthrie 1999).

The Hornsby local government area accommodates the needs of 150,000 residents over an area of 50,990 hectares. A significant portion (65 per cent) is bushland of which 4000 hectares is the Berowra Valley Regional Park (Hornsby Shire Council 2006). The Shire is divided into three main catchments, Lane Cove towards the south, Marramarra towards the North West, and Berowra Creek towards the north which is the focal point of this case study and is the main catchment and estuary of the Shire.

The Hornsby Shire has a broad variety of land uses and contrasting environments representing urban, rural, bushland and riverine settings which contribute to its identity based on the inherent themes derived from the Hawkesbury River (Figure 7) (*Hornsby Shire - Local Environmental Plan* 2001; McPherson & Guthrie 1999)

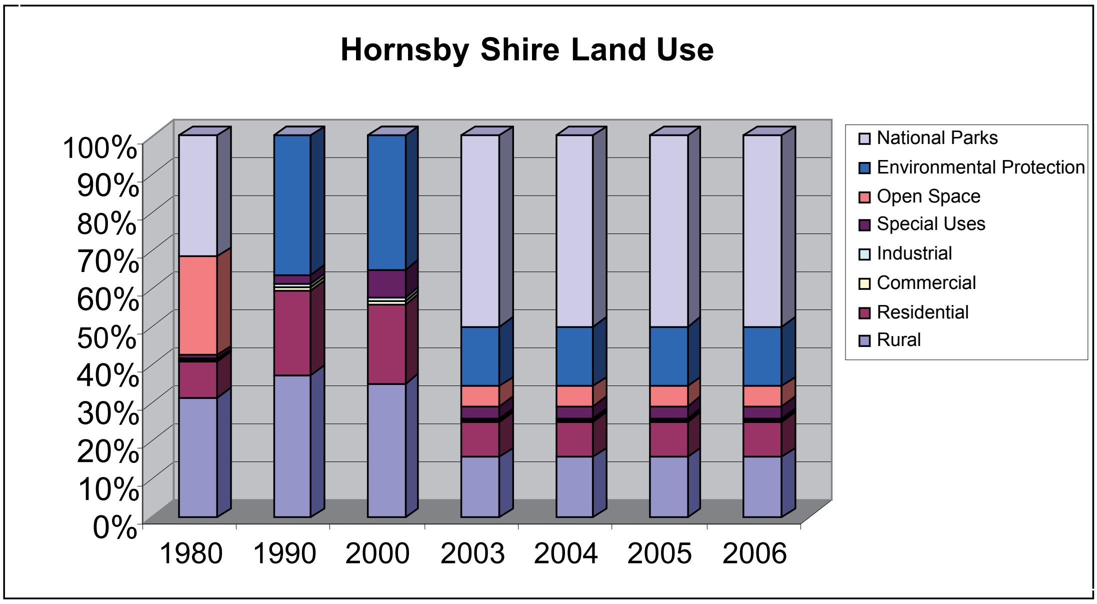


Reproduced with permission from Hornsby Shire Council

Figure 7: Hornsby Shire Urban Settlements Water Cycle at the Berowra Creek Estuary confluence, Hawkesbury River, NSW.

Urban regions are predominantly located along the ridge top areas. The northern region of the Shire is mainly conserved in Muogammarra Nature Reserve and Marramarra National Park. Urban areas to the south and east dominate the ridge tops ('Hornsby Shire Council - Berowra Creek Catchment Stormwater Management Plan - Final Report' 1999) and the western regions of the Shire are dominated by rural-residential and agricultural farmland. The south-west contains large areas of unsewered rural and urban settlements and the north estuarine regions of Berowra, Brooklyn and wider Hawkesbury River includes small farming ventures, market gardens, residential, marinas, boat ramps, aquaculture and fishing (commercial and recreational).

Table 4: Land use areas of Hornsby - the "Open Space" areas from 1990 onwards have been transferred to the Department of Parks and Wildlife Service (Source: 'Special Uses - Open Spaces' 2001).



Development and land use within the Shire is governed by the Hornsby Shire Local Environment Plan (HSLEP) 1994 (*Hornsby Shire - Local Environmental Plan* 2001). The land use zones are depicted in Table 4.

The HSLEP provides a land use framework that prescribes what land use is permissible for development. The objectives are designed to ensure land use is compatible with urban and natural environments.

The Plan divides the Hornsby local government area into ten land use zones ranging from rural and waterways to bushland. There are specific zone objectives that outline the requirements in relation to whether or not Council consent is required for development (*Hornsby Shire - Local Environmental Plan* 2001). The Plan also details specific environmental protection zones that relate to wetlands, river catchments and the Hawkesbury River ('Special Uses - Open Spaces' 2001) as shown in Figure 8.

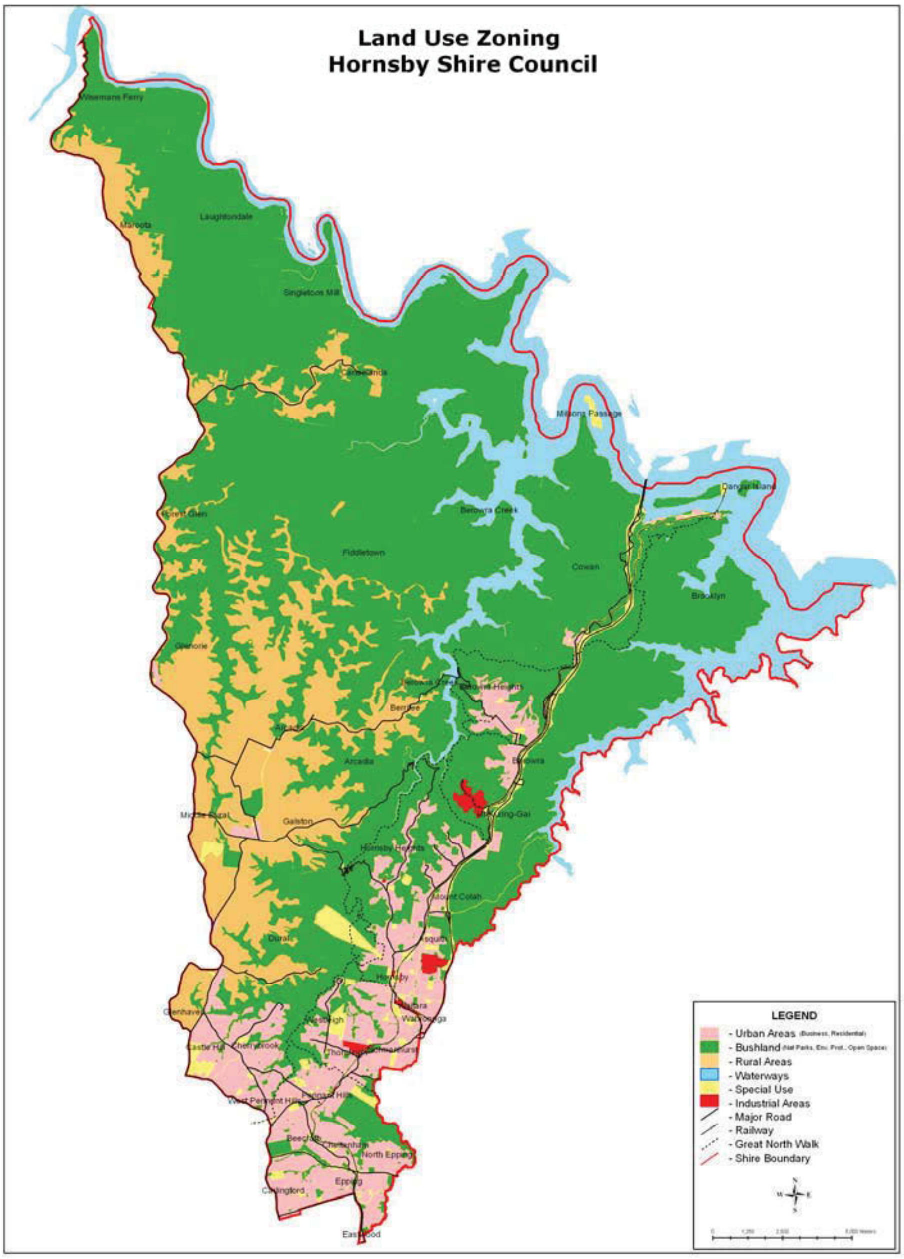


Figure 8: Land Use Zoning Map of the Hornsby Shire local government area (Adapted from *Hornsby Shire - Local Environmental Plan* 2001).

The landscapes within the Shire are characterised by the steep and deep valleys that have remained unaffected by development as shown in Figure 9. These attributes, such as tributaries, creeks, estuaries, and river processes are central to the ecosphere. The local hydrology and its interaction with the Hawkesbury Sandstone and Wianamatta shales geomorphology are important in the context of the water cycle, for there varying water holding capacity and erosion potentials (Chapman & Murphy 1989; Edgerton et al. 2005).

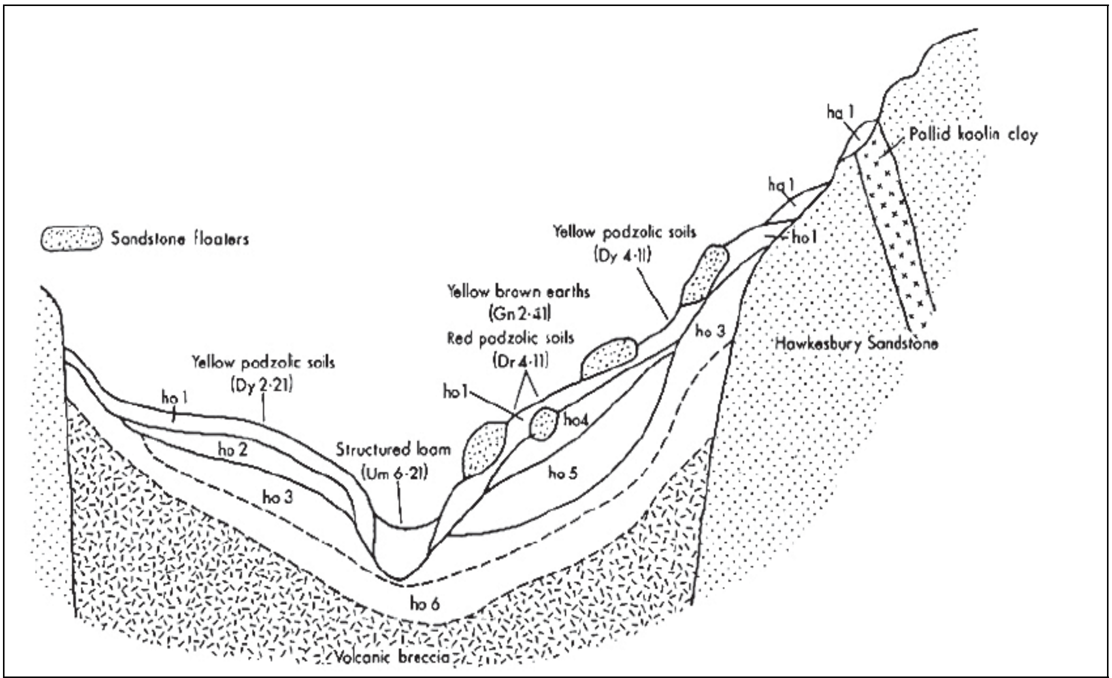


Figure 9: Hornsby soil landscapes profile illustrating the dominant soil types (Adapted from Chapman & Murphy 1989).

In the North West region of the Shire the topography is characterised by the low rolling hills on Wianamatta Group shales on slopes narrow ridges and sideslopes with narrow inclined slopes that dominant the landscape (Figure 9). The soils are generally high soil erosion hazard with a pH range which is highly acid (pH 4.0 to pH 5.0) (Chapman & Murphy 1989).

Creek and natural drainage lines have up to 100 cm of brownish-grey plastic, silty clay. The pH ranges from 5.0 to 6.5. Rock and charcoal fragments are absent and roots are rare. Many drainage lines contain up to 100 cm of sediment deposits covered by organic debris (Chapman & Murphy 1989).

The climate conditions of the Hornsby local government area is temperate with an average annual rainfall range between 1000-1100 mm (*Climate Averages - Sydney Metropolitan Area* 2006).

The maximum mean daily temperature ranges from 27 degrees during the summer months to 17 degrees during the winter months. The minimum daily temperature averages 15 degrees annually and the maximum mean air temperature averages 22 degrees ('Hornsby Shire Council - Berowra Creek Catchment Stormwater Management Plan - Final Report' 1999; *Climate Averages - Sydney Metropolitan Area* 2006; Smith & Smith 1990b). The inner bushland region of the Shire ranges from about 16 degrees in July to 28 degrees maximum in February and 6 degrees minimum in July. The ridges of the two catchments, north and west are exposed to hot summer winds and receive more solar radiation, as a result these areas have higher evaporation rates in contrast to the sheltered slopes and gullies in particular with a south-easterly aspect which create a cooler and more humid climate (Smith & Smith 1990a; Smith & Smith 2006).

Approximately 70 per cent of Hornsby Shire is dominated by bushland reserves that encompass forest, slopes and ridges influencing the precipitation and evaportranspiration water cycle balance. Surveys have shown that approx. 388 native terrestrial vertebrate animals inhabit the Shire of which 10 per cent are currently considered threatened in NSW (Fallding et al. 1994). The majority of these species are birds (Smith & Smith 2007).

The main estuary in the Shire is the Berowra Creek Estuary (Figure 10) formed when rising sea levels flooded the lower Hawkesbury River valley between 6,500 and 10,000 years ago (Coad & Guise 2006). The depths range between five to twenty meters, characterised by a triangular cross-section of deep valleys up stream with wide deltas towards their mouths (Van Senden 1998). The foreshores are characterised by the steep deep gorges extending for over 23 kilometres in a southerly direction (Miller et al. 2003). The catchment is 310 km^2 covering natural bushland with urban and semi-rural developments along the ridges in the upper catchments. Large areas of mangroves occur in the lower portion of the Estuary.

Photo: Neil Keraunos

Figure 10: The distinct steep "V" topography of the Berowra Creek Estuary, upstream towards Calabash Point.

The Brooklyn Estuary is the other estuary within the Shire. The Brooklyn Estuary consists of rocky foreshores with an abundance of common grey mangroves along the western fringe. The leaf biomass for the common grey mangroves is reported to be the highest recorded for temperate forest communities (Saintilan 2003). The dominant seagrass species is *Zostera capricorni*, salt marsh species that populate the region are *Sarcocornia quinqueflora*, and rushes such as *Juncas crausii* are prevalent in the rocky foreshore region (Van Senden 1998).

2.2 Berowra Creek Water Quality Management Strategy

In the early 1990's the Hornsby Shire experienced poor environmental health within the Berowra Creek catchment. Preliminary monitoring showed a significant deterioration in water quality. A major source of pollution was nutrient enriched effluent from Hornsby Heights and West Hornsby Sewage Treatment Plant's (STP's) (Van Senden 1998). Measurement and model simulations showed that annually about 83 per cent of TN load and 22 per cent of the TP load were discharged by the STP's while the remainder was due to diffuse catchment loads and poorly managed urban development. As a result, there was a prevalence of toxic algal blooms that contributed to fish kills in the estuary with the potential risks to public health and biodiversity (*Berowra Creek Water Quality Management Strategy - Healing the Hawkesbury- Nepean Together* 1997).

In response to these concerns Council created a separate Environment Division responsible for integrating environmental science and management strategies. This initiative provided the basis to develop remediation programs by understanding the environmental impacts. Actions initiated from September 1993 to April 1994 led to the establishment of the Berowra Creek Water Quality Management Strategy, these included:

- preliminary water quality monitoring results identified the West Hornsby Sewage Treatment Plant (STP) as a significant source contributing to water quality degradation (identified health risks and fish kills), as a result Council declared a moratorium on new developments that would increase the generation of waste water within the catchment of the STP;
- the Minister for Planning established a Technical Working Party (TWP), comprising representatives from Council and relevant State Government Authorities;
- the TWP confirmed that the two STPs (West Hornsby and Hornsby Heights) were a major source of poor water quality in the Berowra Creek estuary;
- the TWP also highlighted the significant role of polluted urban stormwater, particularly runoff from developing and newly developed residential areas; and
- the participating organisations of the TWP signed a Statement of Joint Intent agreeing to work together to achieve ecological sustainability and the health recovery of the Berowra Creek Catchment .

The implications of the Statement of Joint Intent (SoJI) obliged the New South Wales Government and Sydney Water to upgrade the two sewage treatment plants and Council to utilise water sensitive design concepts in its consideration of future developments to reduce the nutrient concentrations impacting the Berowra Creek Estuary. As a result, Council and the Berowra Catchment Committee drafted the Berowra Creek Water Quality Management Strategy (Snowdon 2006) that outlined current and intended future actions with the aim of establishing water quality improvement, understanding of the catchment, control of point and diffuse pollution and improving community education to achieve ecological sustainability.

The Strategy obligated its stakeholders to work together to improve the environmental health of the Berowra Creek Catchment. The desired environmental values were swimming, canoeing, boating, fishing and the protection of the shellfish industry, threatened species and their habitats. The programs included in the Berowra Creek Water Quality Management Strategy were:

Water Quality Monitoring

Council established a physical/chemical water quality monitoring program in 1994. The program assesses the impact of land use on the waterways within the Shire through time. Site selection was based on land use types (i.e. urban, industrial, rural and estuarine). Currently 37 sites are monitored monthly with a subset of high impact industrial sites monitored every two weeks (*Australian and New Zealand Guidelines for Fresh and Marine Water Quality* 2000). The monitoring assessed trends in water quality from point and diffuse pollution sources and determines the effectiveness of the catchment remediation works. The data was used to calibrate and develop catchment modelling. Data was compared with the ANZECC *Guidelines for Fresh and Marine Water Quality*– protection of aquatic ecosystem and recreational water quality (1992, 2000). The results have showed highly impacted urban industrial, residential and rural catchments reflected poor water quality in regards to nutrients, faecal coliforms and turbidity parameters (Snowdon 2006).

Biological Monitoring

Macroinvertebrates and diatoms were used as biological indicators to assess the environmental health of urban streams. Results have shown that communities are heavily impacted by urban development. Stormwater runoff increases to local streams delivered pollutant loads that contributed to the degradation of aquatic communities (Sargent 2006). The findings have shown that fewer communities were found during Spring than in Autumn and species that were prevalent in most sampling sites were tolerant of disturbed conditions (Coad & Guise 2006).

Imperviousness and drainage connectivity were identified as contributing factors that were impacting macroinvertebrate and diatom communities within the catchments. These results have showed highly impacted urban areas had low species diversity in contrast to communities at rural sites where diversity was generally high.

Biological monitoring was conducted in Berowra Creek Estuary using macrofauna habitats on intertidal rocky shores and mangroves to assess anthropogenic impacts in the Estuary. The rational behind this research was that intertidal and sub-tidal benthic animals are considered good indicators for detecting anthropogenic impacts (Underwood & Chapman 2004) because they were sensitive to environmental perturbations. The study used Artificial Units of Habitats (AUH) because they were less influenced by natural physical conditions in contrast to natural habitats which a more sensitive and more complex in grain size, natural texture and topography (Underwood & Chapman 2005).

The sampling showed over a five year period that sites impacted by urban run-off have developed a more diverse assemblage of invertebrates than were found in the mangrove forest. The findings could have been due to characteristics of the different habitats of mangroves and rocky shores (Underwood & Chapman 2005). An analysis of data has not detected any significant patterns that could be caused by water quality impacts from the catchments. Consequently, modifications had been recommended and were under review that the spatial component of the monitoring should be increased at the expense of the temporal components to identify impacted catchments and focus on potential sources of contamination or disturbances (Willliams & Watford 1997).

Estuarine studies have shown that saltmarsh communities between 1941 and 1992 had declined by 38 per cent due to mangrove encroachment (Saintilan 2003). These impacts have been attributed to elevated sea levels, and increased sedimentation rates due to urbanisation (Saintilan 2003). In response to these concerns a biological monitoring program was developed with the aim of measuring the ecological health of the mangroves and saltmarsh environments in the Berowra Creek Estuary (Coad & Guise 2006). The program examined changes in estuarine wetland vegetation and sedimentation using sedimentation – erosion tables (SET's) (Australian Catholic University 2006).

In spite of relatively high rates of sedimentation in the saltmarsh zone in Marramarra and Berowra Creek, there has been minor elevation in saltmarsh communities since the commencement of the monitoring. Studies have shown that the altered groundwater conditions or the loss of vegetation during fire or other disturbance may be contributing factors in the depletion of saltmarsh communities in the Berowra Creek Estuary (Australian Catholic University 2006).

Photo: Neil Keraunos

Figure 11: Mangrove Communities (*Avicennia Marina*) communities along the Berowra Creek estuary foreshore.

The findings suggest that below-ground processes such as compaction or groundwater depletion due to drought conditions are contributing to the subsidence of the saltmarshes. The results suggest that saltmarshes that show the lowest rates of elevation would be impacted from mangrove encroachment and the saltmarsh would be inundated as sea-levels rise as depicted in Figure 11. This monitoring program has shown trends of sediment movement within the estuary and has shown mangrove and saltmarsh vulnerability to the impacts of sea-level rise. The research has also shown that groundwater plays a significant role in maintaining marsh surface elevations (Australian Catholic University 2006).

Estuary Management Program

In 1995 Hornsby Shire Council adopted the NSW Government Estuary Management Program (Coad & Guise 2006). The Program to date has completed process studies for the Berowra Creek and Brooklyn Estuaries. The Program provided an understanding of the chemical, physical and biological properties as well as economic and social values for maintaining the overall health, functionality and integrity of the estuarine system (Adam et al. 1992).

The Program gave rise to three elements:

- an Estuary Process Study that provided essential baseline conditions of estuarine processes and their interactions, assessing the extent to which human activities have modified or disrupted the estuarine processes;
- a Management Study which uses this information to define management objectives that identify planning issues, physical, chemical, biological, aesthetic, social or economic features, conflicts of uses and the need for conservation and remedial actions; and
- the Estuary Management Plan which consists of actions that need to be undertaken to achieve the estuary management objectives such as conservation, rehabilitation, planning regulations and education (Adam et al. 1992).

Historically algal blooms have been occurring on a regular basis in the Berowra Creek Estuary. In temperate conditions, such as Hornsby, the characteristic pattern of seasonal succession of algal communities showed that diatoms and flagellates rapidly grew in winter and spring followed by green algae in spring and summer which couldn't easily be consumed by zooplankton , such as dinoflagellates and desmids, in late summer and autumn (Bartram et al. 1999). Environmental degradation caused by algal blooms was prevalent in areas where urbanisation and population growth had increased nutrient inflows into surface waters (Mason 1997; Vesilind & Peirce 1983) producing potential toxins harmful to fish, birds and humans (Coad & Guise 2006). In response to these environmental concerns, Council developed an early warning algal bloom monitoring station that measures real time chlorophyll-a concentrations. This methodology determines the level of suspended algae by using a chlorophyll-a photo imaging probe remotely activating an alarm when the chlorophyll-a concentration exceeds 20μg/L (*Hornsby Shire Council - Sustainable Water Cycle Management Strategy - Brief Tender* 2004).

Catchment Remediation Program

The Catchment Remediation program was introduced to remediate water quality from the effects of anthropogenic impacts by constructing water quality devices such as constructed wetlands, trash screening, creek remediation, gross pollutant traps, sediment basins, stormwater reuse systems and landfill remediation (McPherson, Collins & Hor 2005). Constructed wetlands are used widely for biological water quality treatment are generally aesthetically pleasing and provide habitat (Wiese 1998). Established wetlands that are sized around 2 per cent of the catchment (Brown, Beharrel & Bowling 1998) can remove 20 per cent of nutrients from the water column and 80 per cent from soils and sediment particles (Collins & Hor 2005). A 5 per cent levy on rates had been introduced to fund the program. The levy also supported baseline research initiatives such as environmental education, environmental research and hydrological modelling to gauge the performance of the program (Collins & Hor 2005).

Water Conservation and Re-Use

Water conservation programs such as the International Council for Local Environmental Initiatives (ICLEI) Water Campaign (*Water Campaign for Local Government* 2007), Water Savings Plan (*Guidelines for Water Savings Action Plans* 2007) and Every Drop Counts Program (*ICLEI Water Campaign - Milestone 5 Template - Hornsby Shire Water Management Plan* 2004; *Hornsby Shire Council - Water Savings Action Plan* 2006; *Sydney Water Every Drop Counts Business Program* 2007) have been adopted by Council. As a result there has been a 21 per cent (Figure 12) reduction in overall water consumption across Council from the application of water efficiency fixtures, audits, wastewater re-use, and efficient irrigation practices since 1999.

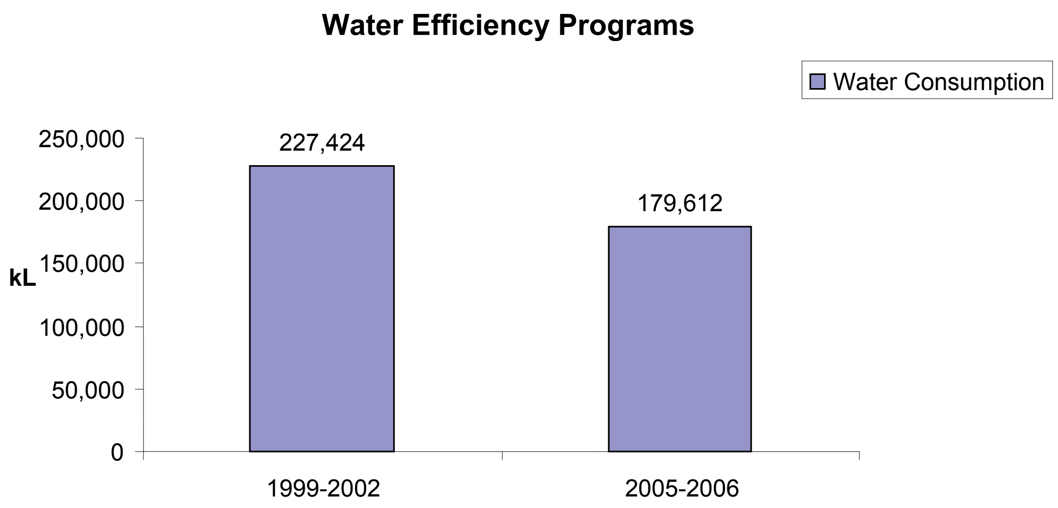


Figure 12: Water savings as a result of water efficiency programs (Source: *ICLEI Water Campaign - Milestone 5 Template - Hornsby Shire Water Management Plan* 2004)

2.3 Sustainable Total Water Cycle Management Strategy

In 2004, the Berowra Creek Water Quality Management Strategy (Edgerton et al. 2005) was revised and broadened to encompass the total water cycle known as the Sustainable Total Water Cycle Management Strategy.

The aim of this project was to improve decision-making for water resource planning and to move towards a more multidisciplinary approach to water management in the context of urban development capacity and capability. The Strategy included the principles of sustainability from the household through to a catchment encapsulating stormwater quality and quantity, water supply, sewerage, recreational planning, social and economic factors as well as consideration of natural environments (i.e. waterways and biodiversity) Mitchell (2004,pers.comm.,29 Sept).

The Strategy produced two key components:

- a strategic action plan (Sustainable Total Water Cycle Management Strategy); and
- a linked Catchment Hydrological Model and End-Use Model.

The initial phase of the project entailed a consultation process with both internal and external stakeholders. This process developed the stakeholders' willingness to influence desired outcomes. It also provided an opportunity to assess the objectives and evaluated the stakeholder responses that influence strategic actions (Edgerton et al. 2005).

The Strategy emphasized the need "to establish a sustainable total water cycle management strategy that enables a holistic approach to the management of water resources" (Edgerton et al. 2005). The strategy proposed to develop an understanding of the current environmental pressures and the future demands on the water cycle for the Hornsby local government area. To achieve this aim it collated information from existing programs such as:

- catchment remediation;
- estuary process studies;
- water quality programs coupled with new actions to enable an understanding of surface; and
- groundwater flows and land use.

The Strategy consisted of actions that were stakeholder and triple bottom line influenced (i.e. environmental, social and economic) with a holistic water cycle focus. The Strategy the main goals included:

- mimicking natural flows;
- water quality enhancement;
- maximising water use and reuse;
- fostering partnerships and community involvement;
- the promotion of the local economy; and
- governance structures to provide incentives.

The principles behind the Strategies framework included Council control, influence and support of stakeholders through community consultation to address areas of concern. The Strategy included plans, and actions and planning processes to achieve the vision.

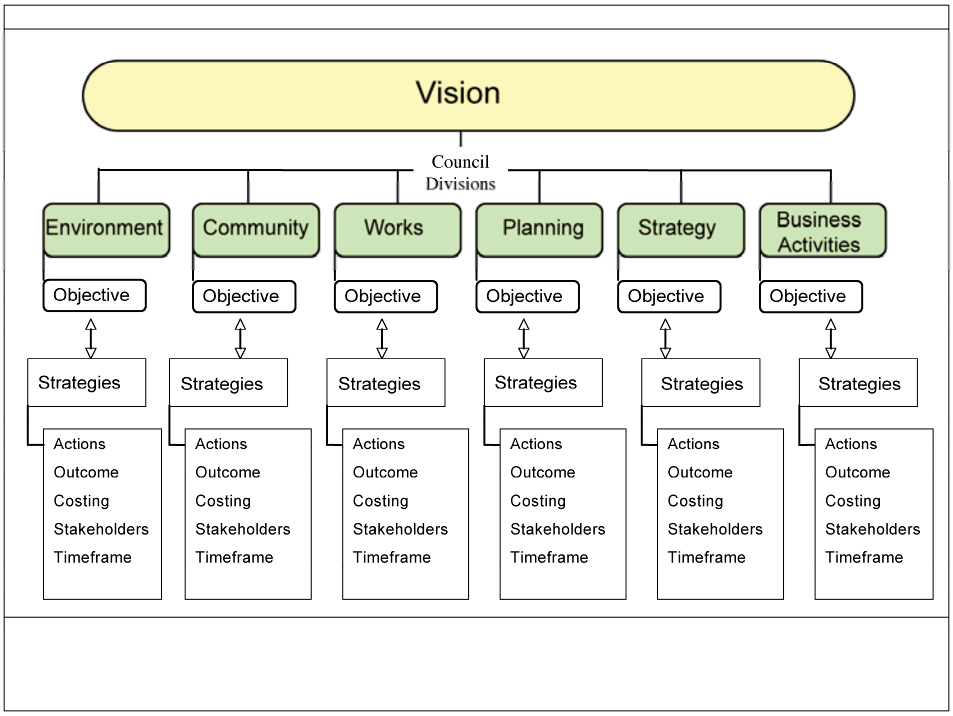


Figure 13: The organisational framework of the Hornsby Shire Council Sustainable Total Water Cycle Management Strategy (Source: Edgerton et al. 2005).

The Strategy was set out so that each Council division could understand where responsibilities lay and what actions they are responsible for, and how their actions would contribute to attaining the overall goal. Each division was allocated strategic outcomes and actions. Each action allocated an indicative cost, stakeholders and timeframe for implementation. The organisational hierarchy of the Strategy is shown in Figure 13.

The second major component of the Strategy was the development of predictive modelling so that a range of future development scenarios could be assessed to assist with long-term planning of water budgets at a catchment level. The modelling provided a management tool that would allow various scenarios relating to water cycle management to be tested. Potential scenarios that could be modelled included landuse change (e.g. rural to urban), impact of deforestation, population density, water and wastewater planning options (including water sensitive urban design), and population growth.

The modelling was developed to run scenarios to predict the capacity and potential of the Shire's catchments and the practices that maybe be implemented to achieve sustainable development (Grayson, Argent & Fowler 2005). The hydrological model (e2) (Grayson, Argent & Fowler 2005) was calibrated using Councils water quality data set spanning a ten year period.

The model predicted the flow, sediment load and nutrients in a stream network over time, operating at daily time steps and reporting over monthly to decadal time scales (Grayson, Argent & Fowler 2005). The main model structure is "node – link" where sub-catchments provide water and material fluxes into nodes, from where they are routed down links. Spatial data, land use, climate, topography and management practices were included with the model framework, modelling scenarios that predict flow and pollutant load by sector and include current water use and the prediction of future water use across the Shire. The End Use Model (EUM) allowed Council to understand interventions made regarding the interaction between people and water in an end use water consumption analysis (i.e. shower, toilet, washing machine, swimming pools etc.).

2.4 Discussion

In the last decade Hornsby Shire Council has embraced the ideology that to manage the environment you must first endeavour to understand environmental processes by investing in scientific understanding. This objective has lead to management practices that can best respond to local environmental pressures. Hornsby Shire Council has achieved this by moving away from the conventional local government role of health and building regulation to an environmental (scientific) management approach.

The Berowra Creek Water Quality Management Strategy was the catalyst for the introduction of environmental programs such as catchment remediation, water sensitive urban design, soil and water management, water quality monitoring, biological monitoring and estuarine process studies. As a result environmental trends and monitoring has shown that these programs have reduced the degradation of habitat, water quality and the occurrence of algal blooms.

The need to broaden and embrace water cycle management has given rise to the Sustainable Total Water Cycle Management Strategy (STWCMS). The ecological principles of the strategy are based on “The Natural Step” (TNS) framework which uses a hierarchical structure to define strategic planning and sustainability. The framework incorporates ecological and social principals to achieve favourable sustainability outcomes by directing problem solving upstream towards problem sources.

The TNS framework further advocates the reduction of wasteful dependence on fossils fuels, metals and minerals that accumulate in nature and a reduction encroachment upon the natural environment (James & Lahti 2004). The TNS focuses on minimising impacts on the natural environment by reducing natural resource extraction, minimising concentrations of substances produced by society, and the reduction of degradation by physical means and human demands. A program of activities was formulated by reviewing activities which culminated in a strategy addressing current issues (Roberts 2002).

The values and objectives behind the TNS model are favourable, however the methodology behind TNS is highly theoretical, with poor criteria on public acceptability and how it can be applied in practical terms and how it is evaluated on a local government level. The principles of the Hornsby Council STWCMS are supported but it is unclear as to how it proposes to maintain a level of sustainability at a local government level. For example, it stipulates that there should be no increase in natural resources extracted, or over-harvesting and that natural resources should be used fairly and efficiently (James & Lahti 2004; Roberts 2002). Although this objective would seem ideal, it lacks specific criteria and performance indicators to evaluate its performance at a local government level.

The strategic goals in regards to water cycle processes (e.g. water balance, precipitation, infiltration, runoff, land use and demographic change) lack depth and are unclear as to how they affect the Shire or how the goals will be achieved. The strategic framework depicted in Figure 13 also lacks strategic ownership, whereby individual Council Divisions are allocated individual strategies with minimal accountability.

The development of predictive modelling has been introduced with the strategy. It proposes to aid planning and land use impact projections for the management of the Shire's water resources. The capacity for catchment modelling to run scenarios and predict environmental change is questionable due to inherent complexities, variability in outputs, data intensiveness, and the requirement for a high level of understanding.

The modelling assertion is to model scenarios, based on monitoring data to support your hypothesis. In reality however, if there are insufficient quality data to support the hypothesis it may hide the uncertainty (Grayson & Argent 2005; Murray et al. 2005) in particular, in hydrological and ecological modelling a large amount of data is required in regards to rainfall, runoff, spatial characteristics, water quality, ecology and land use modifications (Murray et al. 2005). Catchment modelling is invariably suited to catchment scale predictions that perform well at one scale but may not perform well at another scale which could dilute point source impacts (Argent, Grayson & Fowler 2005). The modelling generally produced variable outcomes, was time consuming and most importantly lack integration with GIS. In most applications the modelling architecture was designed by scientists/engineers for scientist/engineers (i.e. modellers) that have high understanding of the modelling framework and other data inputs required (Argent, Grayson & Fowler 2005) and not for managers or end-users. For example to set up a scenario to determine hydrological outputs would require a process involving 94 steps (Jordan 2005).

In general estuary and water quality programs tend to be a "snap shot" assessment of the environment, they are labour intensive, expensive and can only be used in the context of the time and site specific information provided.

Process studies tended to focus on local ecological processes and were restricted by their temporal and spatial scale. Their findings can be both complex and incomplete due to limited resources and can also be too reliant on existing literature which may not be suitable to the subject study area.

The Hornsby Shire Council approach to estuary and water quality assessment was supported and enhanced by a good local water quality and estuary monitoring data set extending over a period of 12 years. This aspect was crucial for instilling confidence in the findings of the estuary process studies, catchment water quality and modelling outcomes, and highlights the importance of long term quality data. In this regard there should be a prerequisite that at minimum of four to ten years of water quality monitoring data should be undertaken before estuary process studies, environmental assessments and catchment modelling development can be undertaken to establish confidence in the modelling outcomes.

Other concerns are directed at the framework of the estuary management model. In general, estuary committees are delegated with the responsibility of initiating actions in regards to the management of the estuary and are mainly composed of local stakeholders/community members. In reality estuary management committees can be biased on specific issues and lacking in scientific and technical expertise to make informed decisions. An effective management makeup would be the integration of scientific and technical specialists, research intuitions, state agencies, state and federal authorities, community stakeholders, business and industry representatives and in house specialists and local government representatives.

Hornsby Shire Council has been innovative in its application of environmental management. It has developed a total water cycle management strategy and integrated research programs in water quality, ecological processes, modelling, biological monitoring, catchment remediation and ecological development assessment and has maintained associations with Universities to further develop Council's programs.

Another facet of water cycle management has been water conservation initiatives introduced by Council. Programs such as the application of water efficiency audits, the retrofitting water efficient fixtures, wastewater re-use and efficient irrigation practices have substantially reduced Council's water consumption by 21 per cent.

In conclusion, Hornsby Shire Council has recognised that the integration of environmental research and management is paramount in achieving ecological sustainability in water cycle management. The challenge is to ensure the findings of research programs are accepted and incorporated into planning and regulative framework instruments.

3.0 Generic Water Cycle Management Strategy for Local Government

3.1 Introduction

Water cycle management strategies should adopt a multidisciplinary approach that provides decision makers and planners with appropriate tools to achieve ecologically sustainable development (Liphadzi 2006). An important element of any water cycle management strategy is to achieve sustainable long-term environmental, social and economic outcomes. This implies maintaining an optimum balance between protection of the environment and the efficient utilisation of water resources (Bennett & Lawrence 2002).

This chapter develops the strategic framework by promoting understanding through active participation, learning and responding to change though adaptive management. The chapter further outlines the organisational structure on how the strategy will be managed, the objectives and priorities and the performance review of the Strategy. The content of the Strategy has been sourced from the findings of the literature review and case study of Hornsby Shire Council. The framework adopts "best practices" in science and management methodologies that are integrated and applied in a holistic manner. As a result the Strategy has been formulated based on the following three themes:

1. **Assessment of the water cycle**; this strategy forms part of a risk assessment where threats and condition define the health of the water cycle (e.g. water balance, water quality, stream flows, ecological health and modelling).
2. **Management of human induced impacts on the water cycle**; this strategy outlines actions to manage human-induced impacts from surface to groundwater by developing effective land use governance.
3. **Conservation of water resources**; this strategy outlines actions to address water consumption, attitudes and barriers in relation to water conservation and reuse and management programs in water conservation practices.

The chapter concludes by incorporating the findings into a Generic Water Cycle Management Strategy presented in Table 9.

Adaptive Management

The Generic Water Cycle Management Strategy incorporates an adaptive management methodology. The adaptive management process is an effective method of increasing understanding of multiple processes through active participation and learning, experimentation, reviewing and responding to change (*Watershed Analysis and Management Guide for Tribes* 2000; Dickinson et al. 2006).

In broad terms, adaptive management is a systematic process for continually improving management policies and practices by "learning from to doing" (Walters 1986). In contrast adaptive management is different from reactive management in that the latter is often unreplicated and lacks statistically valid experimental design, often producing unreliable information (Dickinson et al. 2006; Walters 1986). Passive adaptive management involves long-term monitoring and learning from evolving management strategies (*Adaptive Management Framework* 2005).

Effective management practices should be viewed as a series of evolving improving experiments. The adaptive management process as shown in Figure 14 provides decision making the capability to proceed with uncertainty by specifying actions and continually reviewing management practices to ensure targets will be achieved in regards to the vision, goals and objectives (*C6-Adaptive Management Framework* 2005).

Figure 14: Adaptive Management framework adopted for the Generic Water Cycle Management strategy.

The adaptive management framework depicted in Figure 14 details a nine step process which allows the acquisition and sharing of knowledge to be continuously reviewed and evaluated. Central to this format is the initiation of research involving monitoring and experimentation to fill data gaps and to trial management options to reduce risk and uncertainty in decision making. The process integrates and promotes the sharing of data that aids better communication and confidence between scientists and managers. In addition the pooling of information for a common goal identifies links and gaps between the science and management sectors and community stakeholders (Roberts & Dickinson 2005).

Managers should acknowledge the benefits of using “best practices” based on credible science in the formation of management strategies. Conversely scientists should also acknowledge that scientific knowledge may be incomplete. Therefore, management approaches should adopt the ‘precautionary principle’ in decision making to instil caution and duty of care in managing the water cycle. In contrast the science sector needs to take a more holistic approach in view of its interaction with social and economic values and ensure technical information is “user friendly” practical and relevant for managers.

3.2 Assessment of the Water Cycle

The assessment of the water cycle is an important phase in managing the water cycle. This methodology follows a risk assessment using an adaptive management approach where the health of the water cycle (e.g. water balance, water quality, stream flows, ecological health and modelling) is defined and measured.

Threats to the water cycle are very difficult to define because they are broad and highly complex. The assessment of the water cycle is an essential component of the Strategy, in that it provides a basis for planning, implementing and evaluating management activities. The assessment also provides information that aids informed decision making in the management of natural resources and provides specific information on the existing condition of the various elements of the water cycle. This information can then be used to prioritise areas for existing and future management activities (Eamus et al. 2006b).

The assessment of the water cycle focuses on:

- increased knowledge and understanding about water cycle processes and/or condition to assist in identifying priorities for research and management;
- assessment of the current status of the water cycle elements to establish baseline conditions;
- assessment of the condition over space and time;
- evaluate the performance of management actions by comparing results/findings against guidelines or site specific performance indicators;
- conduct field measurements of physical, chemical and biological parameters;
- remote sensing and GIS integration for mapping specific characteristics of land use and catchment; and
- develop modelling to predict and test pre–European, current and future population expansion scenarios.

To assess the water cycle, an understanding of the water balance, availability and variability of water resources is required. The hydrological water balance of a catchment should include overland flows, subsurface flows, groundwater discharge/ recharge, environmental flows and evapo-transpiration that will affect the ecology and hydrology of lakes, rivers and estuaries. An understanding of basic hydrology processes such as measuring rainfall and its interaction with landuse, measuring streamflow and groundwater flows as recharge and discharge is also important within the water cycle management framework. All the effects mentioned need to be understood to understand how anthropogenic influences the water cycle processes (Hunt 2004b).

The assessment of the water cycle follows three phases; the first phase is to determine the catchment water balance by defining the fate of inflow of rainfall, outflows and changes in groundwater storage. The second phase identifies the major elements that need to be assessed through the collection of data. The final phase is model development calibrated to localised conditions to establish guidelines and benchmarks based on pre-European settlement. Modelling development should evaluate the current condition and prepare modelling scenarios such as twenty year projections of carrying capacity for the local government area.

Local government can influence water cycle interception capability by regulating land-use (i.e. impervious surfaces, vegetation canopy evaporation, and overland flow, soil infiltration to subsurface and to groundwater). Land use and surface runoff play an important role in the water cycle. Catchments that have been urbanised have increased imperviousness (i.e. roadways, dwellings, commercial and industrial areas) and artificial drainage systems effect infiltration, groundwater and runoff. As a result measurements need to be undertaken of impervious coverage of the local region taking into consideration structures such as dams and reservoirs that can impact the natural characteristics of the water cycle greatly (Eamus et al. 2006a).

Figure 15 shows a schematic process involving five areas by which the management of the water cycle can be assessed. These elements include determining the water balance in relation to water storage and the effects of land use, water quality, stream flows, ecological health and the application of catchment modelling.

Strategic Elements

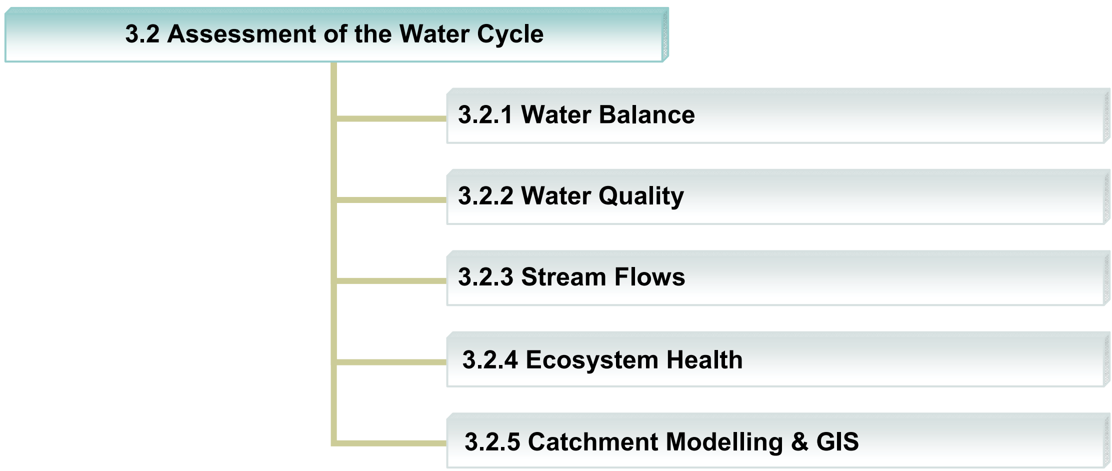


Figure 15: The water cycle assessment elements.

3.2.1 Water Balance

A major consideration in the assessment of the hydrological cycle is determining the water balance. The catchment water balance requires information regarding seasonal and annual fluxes of rainfall, streamflow, evapotranspiration and groundwater recharge. This involves calculating the budget of water inflows, outflows and changes in storage that occur within the catchment. In basic terms this can be simply described as:

"Inflow = outflow + change in storage"

Inflow sources are primarily rainfall, irrigation, surface run on and groundwater inflow (Eamus et al. 2006a). Outflow includes streamflow, deep groundwater discharge, evaporation, plant transpiration and canopy interception loss. Change in storage can include unsaturated soil moisture storage and aquifer groundwater changes (Eamus et al. 2006a).

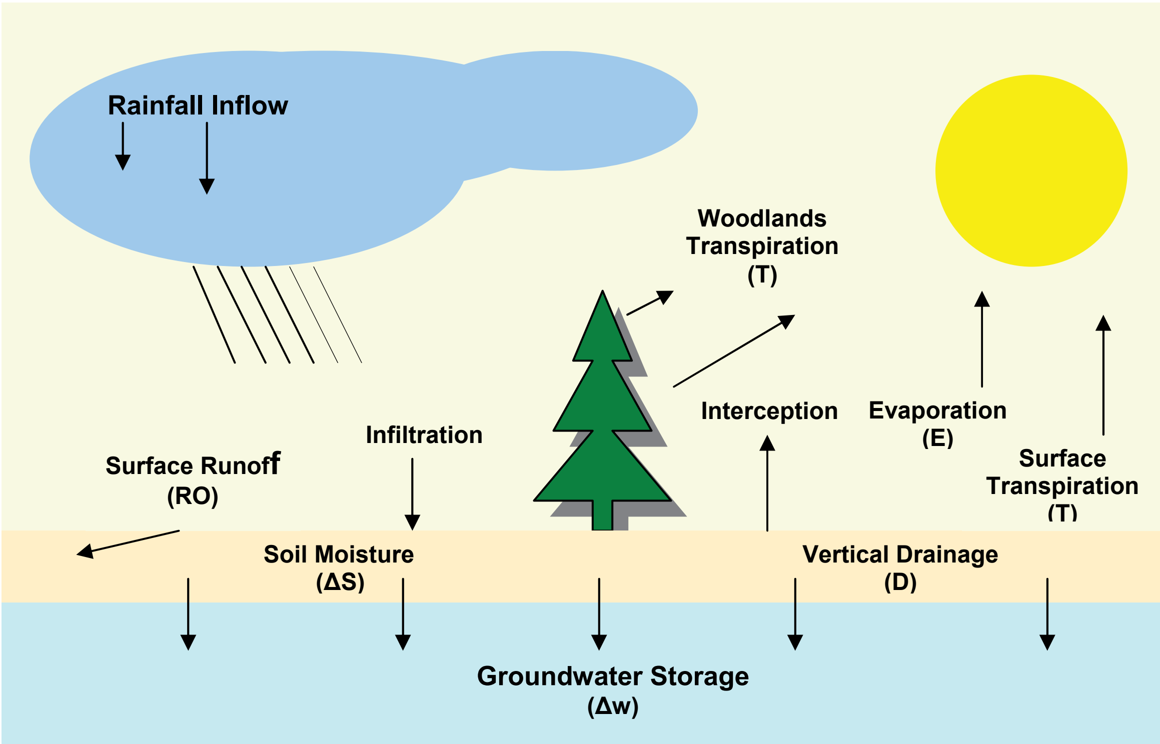


Figure 16: The water balance and its environmental interactions.

To appreciate the interactions between water and biota, the water balance should be viewed locally and on a regional basis as depicted in Figure 16. The localised water balance assessment relates to rainfall that falls directly on the local land surface, this scenario can be determined by;

$$\text{“}P=E+T+RO+\Delta S+D\text{”}$$

where P= rainfall/precipitation, E=evaporation, both soil and canopy interception, T= transpiration, RO= surface run-off, ΔS= change in soil moisture storage and D = vertical drainage below the plant root zone (Eamus et al. 2006a).

The regionalised water balance focuses on large catchments that incorporate lateral processes such as the movement of water overland as run-on into a region or the discharge of groundwater into streams. This application is more suited to a complete water balance for catchments.

The regionalised water balance can be determined by;

$$P=E+T+O+RO+G+\Delta S+\Delta W,$$

where P= rainfall/precipitation, E=evaporation, both soil and canopy interception, T= transpiration, O= surface run-on, RO = surface run-off, G= groundwater discharge, ΔS= change in soil moisture storage and ΔW= change in groundwater storage (Eamus et al. 2006a). The schematic process of the Water Balance is shown in Figure 17.

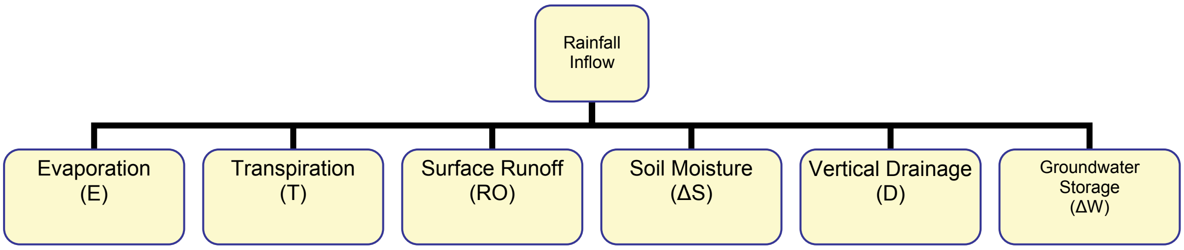


Figure 17: The schematic processes of the Water Balance (Source: Eamus et al. 2006b).

Rainfall Monitoring

Rainfall is the most important input of the water cycle. Forests generally receive the majority of the rainfall supply. Lakes streams and wetlands usually receive their water supply from overland surface flow water and groundwater base-flow. Monitoring of the average rainfall for a catchment should be undertaken to understand the spatial and temporal distribution of rainfall and the amount of input of rainfall the catchment is receiving (Pilgrim 1993). Generally a minimum of 10 years of data is recommended to gauge stream-flow due to the variability of rainfall (Dube 2006). The variability of rainfall, flow and groundwater recharge at daily time steps are important to assist management decisions concerning seasonal water availability to users and the environment (Frost 2002). This can be achieved using rain-gauging evenly distributed across the catchment or sourcing available rainfall data from government authorities, (i.e. Bureau of Meteorology) updated weekly using remote sensing technologies that continuously monitor spatial distribution of rainfall across the region (Eamus et al. 2006a) .

Interception of water movement through the environment

In order to appreciate the underlying principles of the water cycle balance an understanding of the interception of water flows and how water interacts with the environment, e.g. infiltration, overland flow runoff, subsurface storage, groundwater flow, river flow and transpiration from vegetation is required to be assessed (Eamus et al. 2006b). Rainfall interception by the earth's surface is greatly influenced by the type of land-use it falls on (i.e. urban, bushland) and the intensity of rainfall (Figure 18). For example a high proportion of rainfall is intercepted by vegetation during low intensity, short duration rainfall compared to high intensity, long duration rainfall (*Kansas Geological Survey, Geology Extension* 2007).

Runoff occurs when rainfall exceeds the rate of infiltration. The surplus generated amounts to surface runoff or overland flow, these flows travel to streams and rivers. The assessment of runoff is important to determine the volume of rainfall lost from the catchment due to urbanisation and natural landscapes. Surface runoff drives stream flows during rainfall events and water quality impacts in the form of soil, litter, bacteria and nutrients and surface toxicants such as pesticides.

Infiltration of rainfall is extremely variable spatially due to the different types of land-use, and soil composition. The assessment of infiltration of runoff is important to evaluate the variability of water entering the natural environment and how land use practices alter water infiltration.

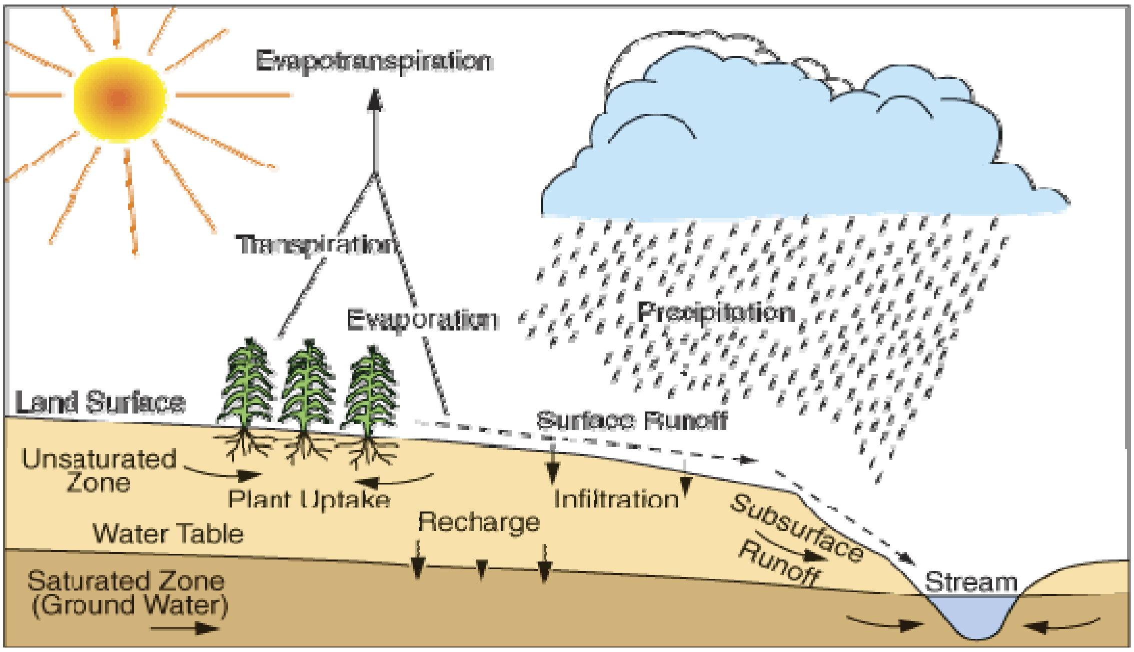


Figure: 18 Groundwater surface infiltration, groundwater storage and recharge (Adapted from *Schematic Section of Groundwater Recharge* 2007).

Groundwater storage and recharge

The amount of groundwater storage and recharge can vary considerably across the landscape depending on the soil type, precipitation rates, types, timing and amount, vegetation, geology and the landscape slope (Figure 19). Urbanisation changes the natural rate of recharge by adding impervious surfaces (i.e.roadways, driveways, rooftops and pavements). Irrigated water diverted from surface water can be an important way of locally increasing recharge to the groundwater in agricultural areas (*Groundwater Management Handbook* 2005).

Groundwater assessment studies should be undertaken to determine groundwater resources in relation to the water cycle balance. In basic terms groundwater is partitioned by permeable geological structures known as aquifers that store and transmit significant quantities of water. The aquitard is a geological structure which acts between an aquifer allowing water to flow slowly. A confined aquifer contains groundwater under overburden pressure restricted between by the aquitard separated from upper soils and water flows. An unconfined aquifer represents the water table level at which groundwater and atmospheric pressure is equal and are typically shallow and have large groundwater yields (*The NSW Groundwater Quality Protection Policy* 1998). Figure 19 illustrates the schematic flow patterns of groundwater storage and recharge.

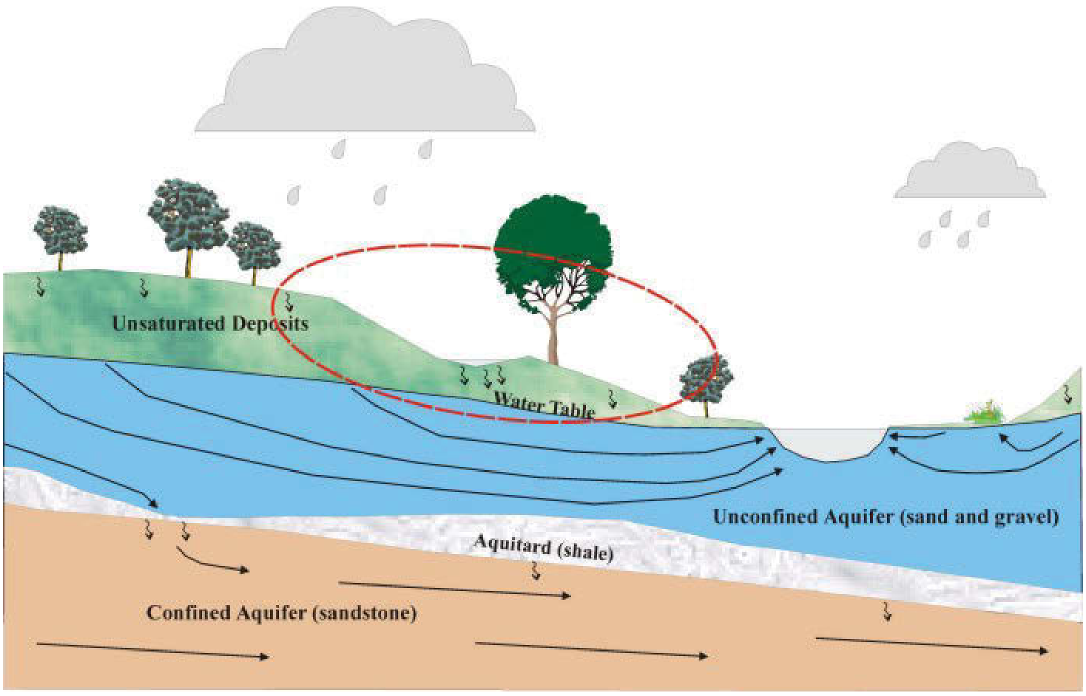


Figure 19: Depicts a schematic layout of the groundwater recharge from a small depression and how water runoff is collected and directed downstream (Adapted from Feinstein & Krohelski 2007).

3.2.2 Water Quality

The focus of this objective is to assess the quality of surface water and groundwater.

Surface and groundwater are interrelated within the water cycle from surface infiltration to groundwater and then into streams linking all the phases of the water cycle (Connell & Miller 1984b).

The water cycle is significantly influenced by the quality of water and its potential productive use. Determining the amount of water available for different uses is further complicated by the considerable variation that exists in quality requirements between and within different user groups and the environment. As a result this objective is aimed at developing actions to monitor and assess water quality at a local catchment level. Actions are directed at improving the management and the identification of emerging water quality issues. Such issues may be how pollution interacts with precipitation, groundwater and runoff (Hunt 2004b; Meybeck & Helmer 1998a).

Declining water quality is generally caused by either point or diffuse pollution sources. Point source pollution is discharged from one identifiable location (i.e. sewage treatment plant, industrial outfall etc). Diffuse or non-point sources are sources which are broad, not defined and are cumulative in nature as such are more difficult to control (Roberts & Dickinson 2005).

Pollution such as nutrient enrichment enters the water cycle through urban surface water, (stormwater) groundwater and sediments or can be introduced naturally. Heavy metals and pesticides can accumulate within sediments and can be toxic to humans and to biota (CRC *The Coastal CRC - NRM Information for Local Governments* 2006).

The term water quality can be interpreted in two phases, these are:

Quality of the aquatic environment

- Chemical concentrations and physical partitions of inorganic or organic substances, composition and state of aquatic biota.

Pollution of the aquatic environment

- Human induced impacts either directly or indirectly by substances that causes harm to living organisms, hazards to human health, aquaculture, agriculture and reduction to economic and recreational and social amenities (Meybeck & Helmer 1998b).

The important aspect of any water quality assessment is to establish a consistent and accredited quality assurance methodology that can be compared spatially and temporally. The temporal scale of water quality assessment can be variable, as some parameters will change more rapidly than others (e.g. seasonally).

Parameters may include physical and chemical indicators, benthic macroinvertebrates, fish, diatoms, riparian vegetation, instream habitat and groundwater dependant ecosystems (Barcelona 1996).

The following factors should be included when designing a water quality assessment program:

- the scale and time period required for monitoring;
- define the study area and number of sampling locations;
- identify resources at your disposal (e.g. money, time, expertise, equipment) and resource limitations that may significantly alter the design and ability to address the objectives;
- incorporate quality assurance/quality control protocols to ensure integrity of the monitoring data (i.e. calibration, methods, audits and record keeping);
- replicate samples within each combination of time and location;
- monitor in the presence and absence of a condition in order to test whether the condition has an effect;
- evaluate the size, densities and spatial distributions of the study area and objects to be assessed; and
- statistical analysis of the data to test against various null hypotheses (*Australian and New Zealand Guidelines for Fresh and Marine Water Quality* 2000).

Surface water quality assessment

Surface water quality assessments provide valuable information as to the health of the catchment, level of environmental impact, ecosystem health, public benefit, welfare, safety and to the level of protection from the effects of pollution. Consequently, a risk based approach to water quality assessment for the protection of aquatic ecosystems should also be applied to surface water (*Australian Water Quality Guidelines for Fresh and Marine Waters* 1992; *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* 2000). The purpose of the water quality assessments is to ’maintain and enhance the ‘ecological integrity’ of freshwater and marine ecosystems, including biological diversity, relative abundance and ecological processes' (*Australian and New Zealand Guidelines for Fresh and Marine Water Quality* 2000, pp. 3.1-2)

Biological systems are extremely variable, and coupled with the marked differences in sensitivity of different ecosystems and biological communities to particular pollutants and other stressors makes it essential that management occurs on an ecosystem to ecosystem basis (Snowdon 2006). Accordingly, water quality monitoring programs should include reference sites which are used to determine the water quality of the local ecosystem free of any anthropogenic impacts. These sites provide a basis from which local comparisons with 'impacted' waterways can then be made. As a result, trigger values are defined and set for disturbed ecosystems. The failure to comply with these criteria would indicate the biological community was under threat.

Groundwater quality assessment

Assessing groundwater contamination involves identifying risks that are unacceptable to human and ecological health (*The NSW Groundwater Quality Protection Policy* 1998).

Groundwater quality varies from region to region and is categorised as occurring in:

- unconsolidated sediments – non cemented sands and gravels commonly found in alluvial valleys, coastal and sand dune systems;
- sedimentary rocks – consolidated formations such as sandstone, limestone and shales; and
- fractured rocks – volcanic and metamorphic rocks such as granite, basalt, shales.

Natural groundwater quality reflects both the mineral content of the host rock through which the water is moving and the duration within the rock. Surface water infiltrates geologic formations (aquifers) to become groundwater and as a result groundwater re-emerges at the surface through springs and rivers.

Generally groundwater quality in Australia has been deteriorating from human activities such as urban and rural development, use of fertilisers and pesticides, leaking sewage systems, septic tanks, leachate from tip sites and contaminated lands (*Guidelines for the Assessment and Management of Groundwater Contamination* 2007). Consequently, the assessment of groundwater contamination needs to evaluate whether it is a threat to human and/or ecological health.

3.2.3 Stream Flows

This objective focuses on the assessment of steam flows (natural flow patterns) that support the natural regime of the water cycle. It also assesses the functionality of streams by monitoring and assessing annual, seasonal and daily patterns to determine the physical and biological properties of stream flows (Souter 2007).

Stream flows generally occur when the rate of rainfall exceeds the rate of infiltration. Urban freshwater inflows can alter the chemical condition of stream flows (i.e. salinity, sediment, turbidity, temperature, nutrients and organic matter) (Beavis & Lewis 2001). Stream flow regime modifications can also affect abiotic conditions such as dissolved oxygen, hydrodynamics and geomorphology, ecosystem connectivity and generally, can result in changes to biota recruitment, survival and growth or depletion of biota (Scheltinga et al. 2006).

Unnatural retention systems such as dams, reservoirs artificial wetlands and rainwater tanks have had a measurable impact on the water cycle by diminishing natural stream flows. As a result processes such as evaporation, soil moisture, infiltration, groundwater storage, have affected the water balance (Hunt 2004a). Unnatural retention systems can further alter water quality by increasing organic load, decrease oxygen content, reduce pH, increase temperature and change a lotic (running water) to a lentic (still water) environments impacting habitat and species (Smith & Pollard 1999). Another important modification is the retention of sediment which is naturally transported by rivers where the majority of the sediment load is deposited in the floodplains. As a result dams and reservoirs impede river flows causing sediment depositions to accumulate within the dams and reservoirs (Hunt 2004a).

Stream flows influence the ecology both downstream and over time, for example ephemeral streams support different species to perennial streams. It is also acknowledged that for riverine ecosystems to function and remain healthy a natural stream flow regime is required to be maintain (Dowsett et al. 2000). Snowmelt fed and spring fed streams generally are more predictable than rainfall fed streams and have less stream flow variability. Habitats in highly variable stream flows that support fish communities, may require flexibility in their feeding and reproductive patterns to support competition and predation. These migratory patterns are essential for breeding and maintaining population levels in high variable stream flows (Smith & Pollard 1999). Intermittent streams have a greater range of physical and chemical variation (e.g.

temperature and dissolved oxygen) and are generally prone to lower species richness in contrast to perennial streams (Eamus et al. 2006a).

Natural stream flows provide aesthetic, recreational, drainage and social benefits. As a result foreshore developments are in demand for their recreational and aesthetic pleasing features. Conversely, however such urban developments adjacent to streams have a deleterious impact to stream flow and riparian habitat causing bank erosion from increased runoff and water quality contamination from sewerage and urban runoff (Debo 1995).

Nationally there is a growing emphasis for an effective compliance and enforcement by governments to enable water managers to determine the degree of connectivity between stream flows and groundwater ('Water - Journal of the Australian Water Association' 2007).

The National Water Commission declared that to manage stream flows effectively, a national framework approach should be adopted for assessing river and wetland health. The management strategy should be rigorous supported by credible factual science ('Water - Journal of the Australian Water Association' 2007).
The Commission acknowledge that:

- freshwater ecosystems are the foundation of our social, cultural and economic wellbeing;
- freshwater ecosystems are declining more rapidly than terrestrial and marine species;
- water flowing to the sea should not be seen as wasted water as it nourishes the water cycle, estuaries, buffer against storms and tidal surges;
- ecosystems are evolving and depend upon naturally variable flows to sustain their existence;
- precautionary principle should be applied in uncertain situations to determine base flow standards on best available knowledge;
- scientific methodologies need to be established to quantify the variable flows needed for each water body by explicitly linking stream flows to specific ecological functions and social values;
- stream flow management should be an integral part of every aspect of land and sustainable water management and recognised by legislation;
- stream flows should be maintain across political boundaries and
- engagement of stakeholders to minimised stream flow depletion.

3.2.4 Ecosystem Health

This objective focuses on understanding the ecological processes of the water cycle as to ensure sustainable management of ecosystem health (Hunt 2004b). Ecosystems regulate the water cycle and are heavily reliant on the complex processes that drive the water cycle. The diversity and productivity of plants, vertebrates, invertebrates and microbes all depend on the distribution and movement of water that distributes and generates the food web (Schofield & Davies 1996).

Ecological processes need to be researched to gain an understanding of the significance of estuaries, rivers, streams, wetlands and groundwater dependent ecosystems. The assessment of ecosystem health needs to define the current condition, identify potential impacts and to ensure ecosystems are managed in a sustainable manner. 'Ecological integrity', as a measure of the health or condition of an ecosystem, has been defined as "the ability of the aquatic ecosystem to support and maintain key ecological processes and a community of organisms with a species composition, diversity and functional organisation as comparable as possible to that of natural habitats within a region" (Roberts & Dickinson 2005; Underwood & Chapman 2004).

The development and use of biological indicators to assess the condition of ecosystem health is essential. Biological indicators should be applied with caution due to their variability and must be highly correlated with the variables that the indicators are measuring (Adam et al. 1992). In addition biological indicators should be specific in there tolerances and not be applied in geographic locations not indicative of there natural habitat (Cranston, Fairweather & Clark 1996).

The assessment of surface ecosystems should describe baseline habitats and species (Adam et al. 1992) and assess the short term variability associated with seasonal cycling. Research into the interactions between physical, chemical and biological processes needs to be undertaken (*The NSW State Groundwater Dependent Ecosystems Policy* 2002) that will include:

- identify vegetation with particular attention to be given to intertidal/riparian zone, seagrasses, mangroves and saltmarsh communities;
- identify and list threatened species, populations, ecological communities and critical habitat that may be present in the locality;
- identify density and species composition in rivers, wetlands and groundwater dependent ecosystems;

- identify aquatic and terrestrial distribution patterns of species, migration and reproductive patterns in relationship to water quality and stream flow conditions;
- assess expected change in biodiversity caused by development increases;
- evaluate sedimentary processes, (i.e. sediment movement, sedimentation rates, and sediment toxicity types);
- assess the impact on benthic infauna through contamination (e.g. heavy metals and organochlorines) from remobilisation of sediments and hydrodynamic impact (i.e. surface flow regime, tidal behaviour, freshwater inputs,) that is likely to affect the ecosystem; and
- develop and apply biological indicators to assess the condition of ecosystem health.

An assessment to identify and evaluate the vulnerability and environmental values of groundwater dependent ecosystems would need to be undertaken (*The NSW State Groundwater Dependent Ecosystems Policy* 2002), this will entail:

- review of existing maps or create maps to identify groundwater dependent ecosystems;
- list known location and type of ecosystem (i.e. wetlands, baseflows, aquifer, cave ecosystems);
- identify type of groundwater system i.e. deep alluvial, shallow alluvial, fractured rock, coastal sand bed and sedimentary rock;
- assess the vulnerability of groundwater dependent ecosystems (GDE) by developing vulnerability maps to identify impact from over-extraction, and contamination (Vrba & Zoporozec 1994);
- develop monitoring techniques to assess the tolerance of GDE’s to water quality variation;
- prioritise the value of GDE’s by assessing the uniqueness of the ecosystem as well as the social and economic considerations and benefits;
- identify major gaps in information and apply the precautionary principle to minimise the impact on GDE’s (*The NSW State Groundwater Dependent Ecosystems Policy* 2002); and
- undertake a review of assessment methods of ecosystem health to gauge performance, acknowledging that scientific knowledge is continually evolving and community attitudes can change to reflect management actions.

Biological Indicator Assessment

A biological indicator can be defined as 'an organism which can be measured in a pragmatic way which diminishes the need to measure a broader, more complex array of variables' (McPherson 2002, p. 19).

Biological indicator assessments should be developed and applied to local government areas to assess the long term biological response of ecosystem health within the water cycle. Preliminary assessments to evaluate the spatial and temporal intensity of the monitoring program should be undertaken to instil confidence in the program (Friedrich, Chapman & Bein 1997).

Catchments that are impacted by urbanisation show a reduction in organism richness, the disappearance of sensitive organisms and the dominance of pollution tolerant organisms. As a result biological indicator assessments provide an indication of status and an early warning of environmental change. They also provide potential causes of the effects of pollutants and can show improvement of ecosystem health from remediation. Information collected downstream of the catchment can be used to summarise the total catchment response from urbanisation (Cranston, Fairweather & Clark 1996).

Taxonomic richness and the composition of communities is an effective means of detecting changes in ecosystem health. Organisms with wide tolerances tend to be less responsive to sensitive environmental changes. The range of possible biological indicators is immense e.g. mammals, reptiles, amphibians, fish, plants and macroinverterbrates etc. Aquatic macroinverterbrates are commonly used and provide an effective indicator for statistical analyses due to their high population numbers, accessibility and life cycle characteristics (Cranston, Fairweather & Clark 1996; Tuft et al. 2000).

Biological indicator assessment programs should consider:

- identification of the best suited organism;
- the appropriate level of identification;
- the predictability of populations;
- the specific responses to pollutants;
- organism indicators should have narrow and specific tolerances; and
- the organism should be abundant and indigenous in the study region (Cranston, Fairweather & Clark 1996; McPherson 2002).

3.2.5 Catchment Modelling and GIS

Catchment modelling has evolved appreciably since the advancement of digital computer technology in the late sixties which has led to major advances in numerical expression and analytical frameworks to address catchment modelling (Chapra 1997).

In general predictive models are mathematical equations based on descriptions of a field condition that describes the relationship between different parameters (e.g. rainfall, soil moisture content, water quality) so that one or more parameters can be calculated based on the values of others. They are often used for calculating scenarios that cannot be easily measured, for example the estimation of a component of the drainage rate beneath the root zone or a prediction of an event that is yet to occur in the future or historical scenarios that have occurred in the past (e.g. pre-European settlement) (Eamus et al. 2006b).

Models can be defined as static whereby the input and output both correspond to the same point in time. Such models are often used as indicators combining various inputs to create a meaningful output. The Universal Soil Loss Equation, (USLE) for example, uses this process by combining layers of mapped information regarding soil, slope and runoff to predict the amount of soil loss from a unit area in a unit time, another example is the DRASTIC model whereby it predicts the vulnerability of groundwater pollution based on mapped information. Other forms of models are defined as dynamic models, these models are used to asses' management scenarios that attempt to quantify "what if" impacts into the future (i.e. population growth, stream flow) (Goodchild 2005) .

The objective of this element is to develop actions that will allow predictive modelling in the fields of catchment water balance, stream flows, and water quality/quantity and ecosystem health. To effectively interpret the application of the modelling outputs a GIS framework should be adapted and applied (Bradford, Zhang & Hairsine 2001) .

To develop a model we need to ask what question is the model intended to answer; the next phase is to develop a conceptual model of the system that shows how the flow process operates and most importantly the collation and analysis of, or the availability of field data (Watson 2007).

If data were spatially limited it would comprise the predictive capabilities of the model irrespective of how mathematically correct or complex the model is, the outputs would be meaningless, however if the data were extensive, the model outputs would produce useful results (Watson 2007).

At the conceptual phase an assessment and selection of available mathematical, models suited for the different elements of the water cycle is made. Model construction involves setting the limits of the subject area to be modelled, the values required and calibration, which involves comparing model predictions with field data and fine tuning the model to reflect real time results.

Catchment models can aid strategic planning by projecting outcomes in relation to urban development to assess the sustainability of land use decisions. This enables the investigation of catchment processes by analysing data at a spatial and temporal scale to predict patterns based on the specific data inputs (Watson 2007). From a water cycle perspective models can effectively provide information to support management decisions on population density threatening land uses, rainfall, surface runoff and groundwater infiltration and storage.

Water cycle balance modelling

Studies have shown that evaportranspiration and runoff is affected significantly by landuse and vegetation cover. Trees generally use more water than agriculture under the same climatic conditions (Bradford, Zhang & Hairsine 2001). As a result water cycle management strategies will have an impact on the catchment water balance.

Water balance modelling involves rainfall being partitioned into interception, depression storage, infiltration and overland flow. Intercepted rainfall will be evaporated or be assimilated into surface flows or stemflow to become depression storage, infiltration or overland flow. Soil infiltration will either be extracted by plant roots (transpiration) will drain laterally as interflow, or will recharge the groundwater that may re-emerge at the surface as springs to become overland flows and exit the catchment as streamflow (Eamus et al. 2006b). Key management factors include controlling evapo-transpiration and the relative dependence on climate, soil and vegetative conditions (Bradford, Zhang & Hairsine 2001).

More simplistic water balance modelling applications are currently under development that focus on assessing the effects of land-use change that requires only vegetation, annual total streamflow and rainfall with the intention of assessing impacts on annual water yield (Zhang, Dawes & Walker 2001). Figure 20 shows a simplistic representation of the modelling processes of the water balance.

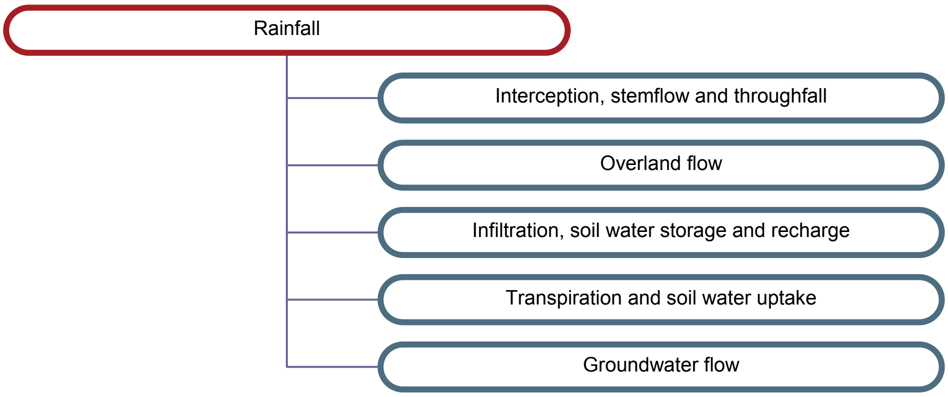


Figure 20: Modelling phases of the catchment water balance.

Catchment modelling

Catchment models are used in strategic planning to form the basis of a decision support system for catchment management decisions by predicting catchment impacts (Church 2005; Edgerton et al. 2005). Catchment modelling frameworks in Australia (e.g. CMSS, AQUALM, CatchMODS, E2, LEMSS, MUSIC) typically integrate a set of models to describe the dominant water quality and water quantity processes within a catchment (Church 2005). These models simulate nutrient and sediment generation and transport and vary considerably in there approach (i.e. pollution export, nutrient loads, evapo-transpiration, surface and soil moisture storage, runoff, interception and retention, streambank erosion etc).

Urban water and End-use modelling

Urban water models differ from catchment modelling approaches in that they address social technical and social economic issues compared to the biophysical focus of catchment models. Urban water models tend to be holistic taking into consideration water balance modelling and end-use modelling (i.e. water supply, stormwater, wastewater infrastructure and water consumption). In general terms urban water balance models simulate inputs, outputs, flow and balances. Their advantage is in there capability for assessing sustainability issues in regards to urban water and the demand of water resources from population increases. Population growth being the major threat to sustainable water management use across the world.

End-use models focus on end-use analysis by classifying water into individual sectors such as residential, non residential and services. The main areas of modelling prediction involve demand forecasting and examining how the community uses their water rather than how much water is used. End-use assessment options simulate the water savings potential of individual demand, planning and aids the decision making process by providing assessment scenarios that considers the total water cycle in a more detailed manner thorough options to achieve sustainable outcomes (Church 2005; Maidment, Robayo & Merwade 2005).

Geographic Information System (GIS)

The adaptability and synthesis of a Geographic Information System (GIS) framework should be integrated into the water balance, catchment and urban modelling outputs. This functionality will allow modelling applications to deliver spatial and temporal outputs. The GIS format would further facilitate practical information on the cause and effect of land use and enhance the understanding of spatial data variability.

GIS defines the spatial characteristics of the physical elements of the water cycle encompassing the shape of land, surface terrain, catchment, and streamflow characteristics giving a three dimensional depiction of catchment morphology. GIS can provide capabilities to represent time varying data and three-dimensional spatial features of the water cycle.

GIS and water cycle modelling can simulate the manner and speed at which water moves through the atmosphere, in surface water and in groundwater to address single issues concerning the water cycle (e.g. streamflows and groundwater aquifer) (Maidment, Robayo & Merwade 2005).

The objective is to apply water balance, catchment and urban water cycle strategic modelling using GIS as the primary interface with users to simulate water cycle responses from land-use and climate variability.

3.3 Management of Human Induced Impacts on the Water Cycle

Globally the water cycle maybe accelerating leading to an increase in extreme weather patterns from the effects of changes in land-use and human activities (*United States Global Change Research Program* 2001; Pittock 2005a). Human induced impacts have altered the physical, chemical and biological characteristics of the natural environment. Generally, nonhuman induced impacts or organisms also impact the natural environment, however these impacts are considered part of the natural system, whether they have detrimental effects or not (Connell & Miller 1984a).

With the advent of industrialisation and consequently population increases has seen the escalation in water demand. Human activities involving manufacturing, fossil fuels, deforestation, urbanisation, agriculture, drainage modification, water abstraction and water storage (damming) has and is continually impacting the water cycle. Globally, 20 per cent of freshwater fish populations are endangered (Cosgrove & Rijsberman 2000) and half the world's wetlands have been either destroyed or altered with a decline of approximately 25 million kilometres of rivers as a result from the construction of dams (McAllister, Hamilton & Harvey 1997).

In northern Europe a significant impact has been the damming of rivers for hydro-electricity generation, which has reduced the migration of aquatic species along the main rivers (Dynesius & Nilsson 1994; Scheidleder et al. 1996). In Norway hydropower increased to such an extent that protection laws for watercourses were introduced in 1973 (Bjorsvik & Faugli 2007). In Japan the construction of dams has depleted freshwater and terrestrial ecosystems to such an extent that only two rivers remain unaffected from 30,000 rivers across the country (Hunt 2004a). The worlds largest deltas regardless of their location are under constant threat from agriculture and irrigation diversions (Cosgrove & Rijsberman 2000).

The increasing demand for water has seen the over-extraction of surface water and groundwater from storage aquifers causing changes to the flow regime to rivers by disconnecting links between groundwater and surface water ('The Value of Water: Inquiry into Australia's Urban Water Management' 2002). As a result, the natural regime of the water cycle is constantly changing (Hollis 1979; Meybeck & Helmer 1998a). Consequently, long-term environmental degradation often outweighs economic benefits (Meybeck & Helmer 1998a).

Defining human induced impacts on the water cycle can be difficult or impossible, for they are complex and have far reaching implications on the water cycle. The management approach needs to assess the impacts on a local scale to develop an understanding of the interactions and processes involved and establish a management rationale.

This strategic element focuses on managing human-induced impacts from surface to groundwater. Strategies are developed in water cycle planning, community education, water quality treatment, protection of groundwater environments and maintaining stream flows. Another significant human induced impact confronting the water cycle is climate change. The effects to climate change management strategies are also included to minimise existing and emerging anthropogenic impacts (Figure 21).

Strategic Element

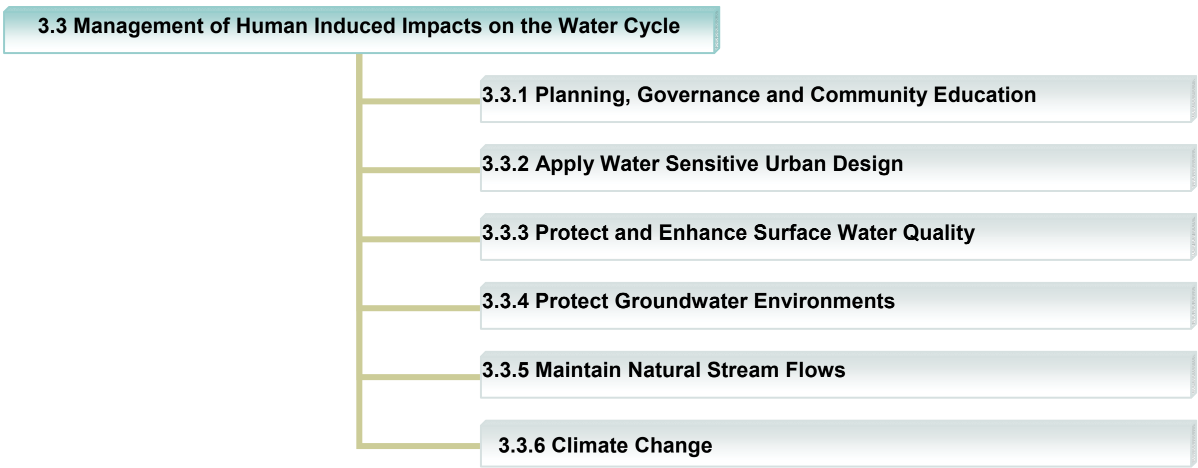


Figure 21: Strategic element for the management of human-induced impacts.

3.3.1 Planning, Governance and Community Education

This strategic objective outlines the objectives and actions that address issues in regards to planning, governance and community educational themes for managing the water cycle.

Planning and Governance

Local governments in Australia are delegated with the responsibility of regulating development. This approach is conducted through usually a specific number of management documents as depicted in Table 5 which are relevant to the management of the water cycle.

Table 5: Local government regulative land use management documents (*Hornsby Shire - Local Environmental Plan* 2001).

Council Plans	Functions
Local Environmental Plan	Primary landuse planning document, it designates what constitutes appropriate use of land such as nominating conservation, development, rural, commercial, residential and recreation. It provides a land use framework for the preparation of DCP's
Development Control Plan	DCP's control specific development activity (i.e. residential, commercial, river settlements) by prescribing planning controls and standards to be applied on development applications.
Plans of Management	Plans of management vary depending on the landuse, character and environments they are designed to manage (i.e. water cycle, wetlands, catchment management, estuary management and stormwater management).
Council Policies	Policies are descriptive statements that detail Council's position on specific issues (i.e. watercourses, sediment and erosion control, drainage management).

Hornsby Shire Council for example recognises six themes within its management plan in order to achieve its vision of *"creating a living environment".* The themes include: working with the community; conserving the natural environment; contributing to community development through sustainable facilities and services; planning for the future of the Shire; supporting the diverse economy and maintaining sound corporate and financial management (*Management Plan 2005/06 -2007/08 - Creating a living environment* 2005).

Programs such as estuary and stormwater management, effluent treatment and reuse, water conservation, water harvesting, water sensitive urban design, ecologically sustainable development and biodiversity management are generally managed in isolation with minimal integration for managing the environment in a holistic and systematic way.

Local governments are "front line" environmental managers and collectively they have a major influence on how natural resources are managed nationally. With ever increasing urban pressure on water resources, local government need to examine effective approaches of managing the environment in a more effective and sustainable way.

The planning challenges facing local government is to ensure ecologically sustainable principles are applied on all water resources in an integrated water cycle balance approach within the planning governance of local government.

Environmental development planning is a vital consideration in water cycle sustainability and is very much the dilemma facing local governments. The water cycle is an overriding theme within developed catchments and is characterised by the complex interaction of climate, geology, groundwater, evaporation, transpiration and hydrology that sustain creeks, rivers and estuaries. The regulation of vegetation and land clearing has a major impact of the surface infiltration, transpiration and groundwater regeneration in relation to the water cycle balance.

Ecologically Sustainable Development

The most difficult issue confronting local government is the achievement of ecological sustainability. The term ecological sustainability is defined as "*the using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increase'* (*The National Strategy for Ecologically Sustainable Development* 1992).

The World Commission on Environment and Development reported *(The Brundtland Report), "Our Common Future"* that sustainable development represented adopting lifestyles within the earth's ecological capacity. The 'Brundtland Report 1987' defined sustainable development as that which 'seeks to meet the needs and aspirations of the present without compromising the ability to meet those in the future' (Goldie, Douglas & Furnass 2005, p. 2). The report stressed that the current escalation of economic growth could not be sustained ecologically without significant changes in attitudes and strategic actions. In response to this initiative Australia has adopted and refined the concept of sustainable development, taking into consideration our local environment, the aspiration and values of the Australian community and the environmental, social and economic values.

In 1992 the Australian Federal Government released the National Strategy for Ecologically Sustainable Development (NSESD). The Strategy included a wide range of stakeholders from community, conservation groups, scientific organisations and state and federal governments. The NSESD considered such issues as climate change, biodiversity conservation, urban development, employment, economic diversity and international considerations were the basis for the National Strategy (*An Overview of the National Strategy for Ecologically Sustainable Development* 1992).

The following principles were integrated in the National Strategy for Ecologically Sustainable Development. The Strategy was adopted by Federal, State and Local Governments in December 1992. The NSESD recognises the need to:

- integrate economic and environmental goals in policies and activities;
- ensure that environmental assets are properly valued;
- provide for equity within and between generations;
- deal cautiously with risk and irreversibility; and
- recognised the global dimension.

Agenda 21

The concept, referred to as *Agenda 21* was adopted at the "Earth Summit" in Rio Janeiro in June 1992. The United Nations Conference on Environment and Development (also referred as the "Earth Summit") presided over the signing of two new global Conventions, on Climate Change and Conservation of Biological Diversity and the adoption of a declaration on the principles of sustainable development. Agenda 21 sets out actions that nations, communities and international organisations can strive to achieve towards the goal of global sustainability in the new millennium. The Commission on Sustainable Development (CSD) was established during the Conference to review progress in the implementation of Agenda 21 (*Agenda 21 - Sustainable Development* 2004).

The relationship between the National Strategy for Ecologically Sustainable Development and Agenda 21 is obvious. Both strategies provide a framework for an ecologically sustainable decision making process. In contrast Agenda 21 approaches the ecologically sustainable strategies on a global perspective, focusing on actions that individual governments need to initiate to ensure that a desired sustainable outcome is achieved (*An Overview of the National Strategy for Ecologically Sustainable*

Development 1992; *Agenda 21 - Sustainable Development* 2004). Agenda 21 strategic programs focus at implementing sustainable development and to better integrate environmental, economic and social goals at a local level by building upon existing local government strategies and resources. Strategies include corporate plans, vegetation plans, management and effect on land use developments such as land clearing, surface sealing, pervious to impervious surfaces, clearly effect the precipitation, evaporation, infiltration , groundwater and surface flow capabilities of the water cycle in catchments (*Australian Guidelines for Urban Stormwater Management* 2000).

Community Education and Knowledge Exchange

Community education and knowledge exchange plays an important role in managing the water cycle. Valuing local knowledge and listening to community values contributes to social and community harmony in achieving strategy goals. Community activities such as increased impervious areas (e.g. roads, roofs, paving), the removal of riparian vegetation adjacent to watercourses and the extraction of groundwater and the degradation of aquatic habitats in creeks and wetlands are significant environmental impacts. Local government can influence community behaviour through knowledge exchange by informing social values, standards, laws, regulations that will enhance the communities understanding and will encourage responsible behaviour.

This strategy focuses on promoting “water” confidence within the community, ensures the objectives of the water cycle strategy are transparent and are performance based. It strives to engage the community through education awareness and knowledge exchange programs and by fostering research and partnerships to advance the concepts and values of water cycle management.

Community education further increases community ownership and fosters acceptance solutions that reflect the community’s life style values and priorities (Allison & Francey 2006).

3.3.2 Apply Water Sensitive Urban Design

Since the early 1990’s there has been an increasing interest to manage the urban water cycle in a more sustainable way. These initiatives are based on key sustainability principles of water consumption, water recycling, waste minimisation and environmental protection (Allison & Francey 2006). The integration of management of the urban water cycle with urban planning has multiple environmental benefits including improving urban landscape, reducing pollutant export, retarding storm flows and reducing requirements on water resources (*Australian Guidelines for Urban Stormwater Management* 2000).

The application of Water Sensitive Urban Design (WSUD) seeks to minimise the degree of impervious surfaces and mitigate changes to the natural water cycle, through on-site reuse and temporary storage of water in an urban environment. The WSUD concept also focuses on minimising the use of formal drainage systems, encouraging infiltration and stormwater re-use ('Chapter 5 Water Sensitive Urban Design' 1999). This design approach integrates major and minor flow paths within the landscape and regards stormwater as a resource rather than a burden. It also considers all aspects of runoff within a development and includes natural, social and cultural environments (*Australian Guidelines for Urban Stormwater Management* 2000). Critically, the WSUD concept focuses on the drainage characteristics on new developments only with minimal appreciation on the functional elements of the water cycle as a holistic system.

The key principles of water sensitive urban design on new developments are applied to the Strategy, they include:

- hydrological balance by using the natural processes of storage, infiltration and evaporation;
- environmentally sensitive area protection;
- restoration and enhancement of urban streams and estuarine waterways;
- minimisation of impact from the urban development;
- increase the diversity of natural habitats within the suburban landscape;
- increase and sustain water cycle balance;
- enhancement of natural amenities; and
- integrate planning control instruments to achieve an ecologically desired outcome.

3.3.3 Protect and Enhance Urban Surface Water Quality

This strategic objective focuses on the control, enhancement and minimisation of diffuse and point source pollution of surface water.

An integrated approach to water cycle management is essential for treating surface water quality. Urbanisation has modified the natural landscape and consequently the catchment characteristics by changing vegetative ground cover to impervious surfaces such as roadways, roofing, driveways, paving and land levelling (*Australian Guidelines*

for Urban Stormwater Management 2000; Roberts & Dickinson 2005). As a result these changes have contributed to higher runoff volumes and increased amounts of organic and inorganic material, suspended solids and nutrients discharges to receiving waters ('The Value of Water : Inquiry into Australia's Urban Water Management' 2002).
Natural catchments can absorb and infiltrate up to 90 per cent of rainfall compared to urban catchments which can only hold around 10 per cent (Sharpin 1995). The concentration of surface water pollutants (e.g. Suspended Solids, Total Phosphorus and Total Nitrogen) under wet conditions is significantly higher than low flow concentrations often exceeding the ANZECC (2000) water quality guidelines ('The Value of Water: Inquiry into Australia's Urban Water Management' 2002).

Rural, industrial and residential land uses are generally considered a major diffuse source of surface water degradation. As a result, the land use changes have dramatically affected the biophysical processes and the ecological cycle which permeates throughout the water cycle from headwaters to receiving waters (Morse, Junor & McVey 2004).

Sedimentation is considered a significant water quality issue. As a result, hundreds of tonnes of sediment are generally released attributed from urban development into the water cycle for every hectare of land disturbance. Such impacts can effect drainage patterns, infiltration characteristics, destruction of habitat and the degradation of amenity values to waterways and estuaries (*Australian Guidelines for Urban Stormwater Management* 2000; Morse, Junor & McVey 2004).The urbanisation of catchments has also exposed the water cycle to chemical, microbial and biological pollution. Accordingly, strategic management plans for the protection and enhancement of surface water quality falls into two stages. The first stage includes construction sites or disturbed areas and the second details strategic actions to enhance established urban catchments.

Construction Sites or Disturbed Areas

At the construction stage, erosion and sediment control practices (i.e. Soil and Water Management Plans) should be applied to mitigate the effects of sediment laden runoff during construction.

These management practices provide screening of sediment laden runoff coming from the disturbed areas and controls wastes, chemicals and fuels. Such mitigation practices control on site soil erosion and the movement of water onto, through, and off the site during the construction phase. The following principles underline "best practice" in soil and water management (Morse, Junor & McVey 2004):

- minimise the extent of disturbed areas divert runoff from undisturbed catchments around work area;
- topsoil stockpiling stripped from the construction site shall be kept away from drainage lines;
- screen and capture contaminated surface waters as close to the source as practical by retention basins and sediment fences at the downslope of the disturbed areas; and
- rehabilitate and landscape the site and rapidly revegetate disturbed areas with preferably indigenous plant species (Morse, Junor & McVey 2004; Tropman 1996).

The success of the above approach is heavily reliant by:

- appropriate planning prior to the commencement of works;
- monitoring and maintenance of management practices and education; and
- diligence of contractors on the correct installation and management of sediment controls/ devices (*Australian Guidelines for Urban Stormwater Management* 2000).

Established Urban Catchments

Surface water quality enhancement in established urban areas aims to minimise the amount of pollution entering streams and waterways. Generally it is more efficient to control surface water pollution at the source by applying a combination of different treatment measures that consist of a three tier treatment process.

- Primary: screening gross pollutants, coarse sediment (e.g. litter basket, gross pollution trap).
- Secondary: finer particulates and filtration (e.g. grass swales, sand filters).
- Tertiary: filtration, biological uptake and adsorption (e.g. wetlands, ponds)(*Australian Guidelines for Urban Stormwater Management* 2000; *Total Watermark* 2004).

3.3.4 Protect Groundwater Environments

Groundwater management is an integral part of the water cycle. The hydrology of groundwater is more complex than surface water because it's not visible and is not clearly understood. Groundwater resources are threatened by over-extraction, inadequate recharge and contamination from land use practices as shown on Figure 22. The traditional approach to managing groundwater in urban environments has been to disregard its value in its natural state and to divert its flow from impacting the built environment (*The NSW Groundwater Quality Protection Policy* 1998).

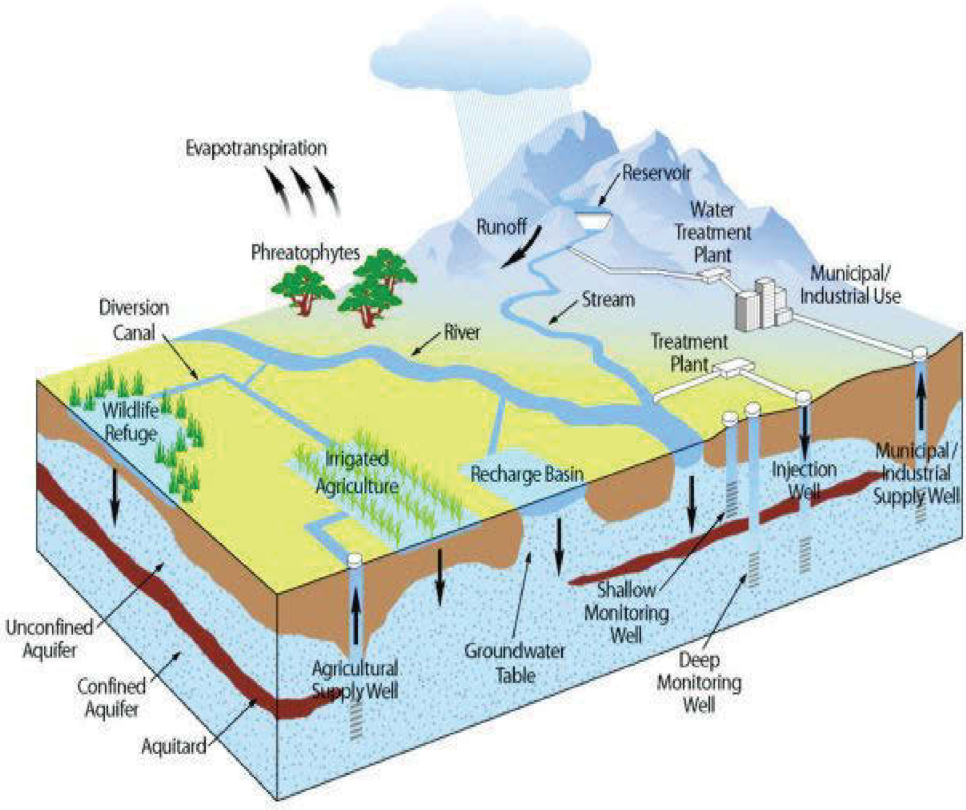


Figure 22: The interactions of the effects of groundwater in an urban environment (Adapted from *Groundwater Basics* 2007)

Urban impacts such as large subsurface multi-storey developments, tunnels and foundations for bridges all contribute to the altering of natural groundwater movement by dissecting and disrupting ancient groundwater aquifers. Human induced impacts affect the quality of groundwater in urban and rural environments and its dependent ecosystems. Natural wetlands, streams and rivers recharged by groundwater have been degraded and rising groundwater tables have reduced the quality of soil and river water (*Guidelines for the Assessment and Management of Groundwater Contamination* 2007). Groundwater protection is also important for the health and economic wellbeing of communities as a source of drinking water, irrigation for agricultural sectors and to support and sustain biodiversity (Vrba & Zoporozec 1994).

The need to develop management strategies to identify, quantify, predict and manage impacts of groundwater resources from intensive land use modifications is vitally important to the sustainability of groundwater environments. It is equally important to develop effective groundwater management strategies that incorporate groundwater vulnerability assessments to evaluate the environment risk.

The assessment of groundwater vulnerability requires groundwater vulnerability mapping assessment criteria to be established to facilitate the process of groundwater mapping and risk assessment of groundwater resources (Aller et al. 1987). The assessment of high risk areas incorporating computer based tools (i.e. DRASTIC), should be integrated with GIS spatial systems to identify groundwater zones and risk regions (Souter 2007). These technologies are becoming more common and should be accessible by local governments to ensure that groundwater dependent ecosystems and groundwater resources are managed efficiently for present and future generations.

3.3.5 Maintain Natural Stream flows

The management and preservation of stream flows and their interaction from surface water to groundwater between catchments and river systems are crucial to the sustainability of the water cycle. Natural stream flows, flooding and drought are natural occurrences that contribute to the sustainability of the environment, and to the prosperity of economic and social communities. (*Australian Guidelines for Urban Stormwater Management* 2000; Pierson et al. 2002).

The term stream flows or environmental flows refers to fresh water that is maintained for environmental purposes for the sustainability of biodiversity of rivers, wetlands, groundwater and by and large the water cycle. The diversion and modification of stream flows can alter the flow regime of surface and groundwater systems which can influence the health of downstream aquatic ecosystems and ultimately the water cycle (Pierson et al. 2002; Roberts & Dickinson 2005).

A sustainable allocation of water for the community and for environmental needs is essential to maintaining natural stream flows, this however can only be achieved by natural stream flows being recognised formally under law as a legitimate use of water for the sustainability of the water cycle and ecosystem health (Roberts & Dickinson 2005).

Human induced impacts that affect the flow regime include:

- dams, weirs and tidal barrages;
- domestic water supply and water treatment works;
- sewage treatment plants inputs and inter-catchment transfers;
- industry and irrigation water demands;
- catchment modification that alters the rainfall-runoff process (i.e. clearing vegetation, impervious catchment surfaces and reduced base flows);
- watercourse modifications/realignment, straightening;
- natural instream obstructions by sedimentation and debris accumulation e.g. woody debris, litter; and
- groundwater withdrawals (*National Principles for the Provision of Water for Ecosystems* - 1996).

3.3.6 Climate Change

This objective focuses on developing an understanding of the implications of climate change to the water cycle and evaluates what options are available to local government. The objective integrates water cycle and climate change strategies with urban planning and develops an understanding of the implications of climate change in regards to the water cycle. The objective further develops actions to encourage and develop community awareness on climate change and greenhouse associated issues in relation to the water cycle.

The term climate change can be defined as a directional change in climate, beyond natural bounds of variability that is attributed to human activity which has altered the composition of the atmosphere (Newton 2007).

The water cycle has been identified as the highest scientific priority for global change research (Rind, Rosenzweig & Goldberg 1992). The physical phases of water from solid to liquid to gas involves the transportation and conversion of energy that effects the radiative climate balance that changes the water vapor in clouds. This process acts as an integrator within the global climate system, controlling climate variability and maintaining a suitable climate for humanity and all life forms (Lawford et al. 2003).

In basic terms, global warming applies to an atmospheric condition which has contributed to temperature increases in the lower atmosphere which are believed to be the result of the accumulation of gases such as carbon dioxide, methane, nitrous oxide, chlorofluorocarbons and ozone (Jones et al. 1990). These gases are natural elements of the atmosphere known as “greenhouse gases” absorbing harmful short wavelength, high energy solar rays acting like a pane of glass in a greenhouse. The atmosphere is largely transparent to incoming short-wave (or ultraviolet) solar radiation, which is absorbed by the Earth's surface (Allaby 1996). Much of this radiation is re-emitted as heat energy at long-wave, infrared wavelengths.

The atmospheric natural cycle process keeps the temperature of the earth stable and in balance. The absence of the greenhouse effect would result in the average temperature of the Earth falling to $^{-}18$°C (Jones et al. 1990) . Portions of this energy escapes back into space, however a majority of the wavelength is reflected back by a layer of gases composed of carbon dioxide, methane, nitrous oxide, halocarbons, and ozone in the atmosphere. This heating effect is the basis of global warming.

Under normal conditions the level of carbon dioxide in the atmosphere remains constant, and trees absorb the same amount of carbon dioxide that people produce. But in recent decades, and with the advent of the industrial revolution, population increases, deforestation and urbanisation have contributed to high carbon dioxide levels being emitted to the atmosphere. Reports have suggested that carbon dioxide levels have increased by 26 per cent between 1860 and 1986 (Jones et al. 1990).

The increased use of fossil fuels such as oil and gas by industrial, domestic and transportation sources, coal, and the slash-and-burn clearing of forests have also been contributing factors in the carbon cycle. Estimates have shown that by the year 2100, atmospheric carbon dioxide concentrations would increase by 75 per cent higher than the pre industrial estimate of 280 ppm in 1750. As a consequence of these impacts it is predicted that the atmospheric temperature will rise between 1.4°C and 5.8°C by 2100 mostly from thermal expansion of the oceans effecting polar temperatures increasing sea level rise from 9 cm to 88 cm flooding many low lying areas across the globe (Pittock 2005c).

The water cycle would be impacted by climate change through increases in water demand due to drier seasons, more extreme rainfall events , increased eutrophication due to high nutrient loadings, low water flows and high temperatures (Pittock 2005a).

Further changes would include changes in groundwater recharge, soil moisture and runoff, changing precipitation, vegetation and changing land use patterns (Lawford et al. 2003).

Modelling studies have shown that rising levels of carbon dioxide would trigger higher temperatures at the Earth surface and the troposphere causing changes to water vapour, cloud cover and solar radiation (Pearce 2004). These changes have an impact on the evaporation and precipitation processes of the water cycle globally causing the discharge of fresh water from rivers to rise by 15 per cent. In contrast an increase in evaporation levels will reduce the moisture content in soils up to 40 per cent in many semi arid parts of the world, including north-east China, the grasslands of Africa, the Mediterranean and the southern and western coasts of Australia. The biggest increases in river flows predicted are directed at the populated tropics and the far north of Canada and Russia. Rivers such as the Ob in Siberia and the Yukon in Alaska are projected to increase in flow by 42 and 47 per cent respectively by the end of the 23rd Century (Pearce 2004).

Current scientific research does show that changing global temperatures will affect the water cycle through increases in average precipitation (rain or snowfall) and evaporation by 1 to 9 per cent by 2100 causing river flows to rise and fall (Pittock 2005b). Further studies have shown that global flows will increase by 4 per cent for every one degree celsius rise in global temperature and has been attributed to river flow increases in North and South America and Asia (Pearce 2004). In 1950 the United States accounted 23 per cent of total irrigation water from groundwater resources whereas in 2000, groundwater withdrawals accounted for 42 per cent due to increased temperatures (Pittock 2005a).

Global climate change is of strategic importance due to the evolving minute changes of global climate. As a result there is a need to adapt water cycle management cautiously to ensure water resources are ecologically sustainable and are socially acceptable. Water cycle management strategies would need to consider hydrological regimes, water availability and reliability, decreasing stream flows and soil moisture in relation to climate change to enable informed, quantitative decisions to be made (*Climate Change Science* 2005).

Current techniques in climatic forecasting need to distinguish from natural climate variability and anthropogenic induced climate change. Research should be focused on understanding the frequency and magnitude of extreme rainfall events and the application of conceptual and numerical models to predict global change. Hydro-climatic information should provide information regarding likely landuse, ecosystem hydrological water quality changes and to adapt existing management strategies to achieve desired sustainable outcomes (Dube et al. 2006). Further, the effect of climate change to accurately project impacts on the water cycle is not clearly understood in relation to radiative balance and cloud structure (Lawford et al. 2003)

Broadly, reports such as the Stern report commissioned by the British Government examined evidence of climate change on a global scale and estimated the costs of action and inaction in regard to reducing greenhouse gas emissions and its impacts on both developed and developing countries England (2007). The report included the implications for energy demand and emissions; costs and benefits of mitigation and adaptation to a low-carbon global economy. The report concluded that stabilising the climate is costly but manageable and delay would be precarious, action requires to be taken now, to avoid serious impacts on growth and development. It further outlined that actions should be uniform across all countries and does not need to limit the aspirations of rich or poor economies. The key areas included: emissions trading, technology cooperation, action to reduce deforestation and adaptation assistance for developing countries that have not contributed to global warming (*Stern Review: The Economics of Climate Change* 2007; Mandelc 2007). The findings surprisedly had minimal exposure to the implications of climate change to the water cycle.

The political scepticism of climate change is driven by unqualified advocates supported by the fossil fuels industry. The main focus for science and governments is to engage more actively between science peer–review process to enable policy makers, industry and the community to make inform decisions concerning the effects of climate change.

3.4 Conservation of Water Resources

This strategic theme focuses on the conservation of water resources. It develops strategic actions in regards to water consumption, community education, attitudes and barriers in relation to water re-use and proposes management programs to use water more efficiently (Figure 23).

Fresh water supply is the most significant issue confronting the 21st century. Population growth and economic development globally are driving an increase for demand in water resources that has more than tripled over the last 50 years.

Strategic Element

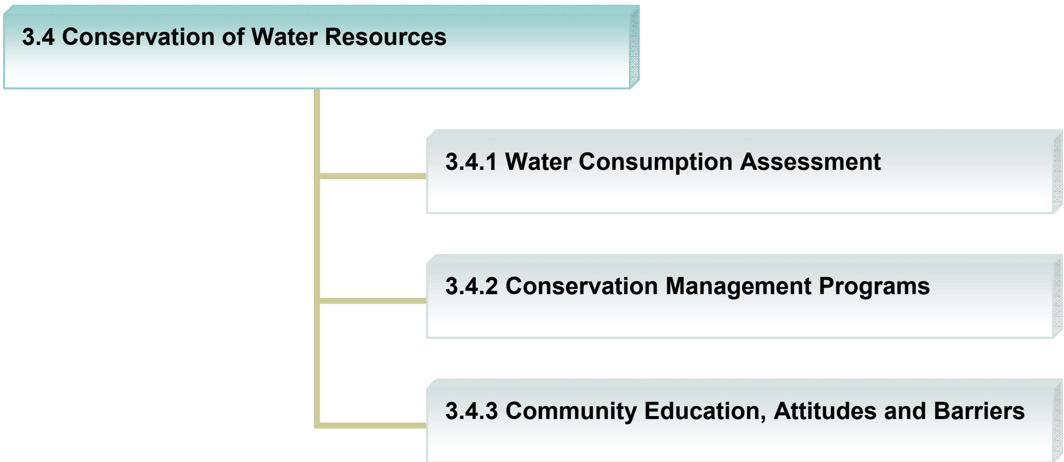


Figure 23: Strategic element outlining the strategies for conservation of water resources.

In Australia the population is highly urbanised with 65 per cent living in capital cities located within 100 km of the coast. As a consequence, the supply of water will become a major issue for future expanding urban settlements. The prediction is that the population will generally increase dramatically from 20 million to 27 million by 2050 ('Australian Bureau of Statistics - Water Account Australia 2004-05' 2006).

As fresh water demand increases and consequently the supply becomes less reliable, local government must make important decisions on behalf of the community regarding water conservation. It is safe to assume that most economical and productive sources have already been exploited. Scope exists however to implement alternative water conservation and re-use measures which have enormous potential for replacing potable water sources which may be a necessity and not an option in the future. This also means that less water is extracted from our natural resources.

Approximately 37 per cent of reticulated water in Australia is used for garden watering where collected stormwater could be utilised. With low levels of rainfall and severe droughts, the demand for water conservation is more vital than ever ('Australian Bureau of Statistics - Water Account Australia 2004-05' 2006).

Generally, the implementation of water reuse schemes in Australia has been poor in comparison to other countries. The conservation, recycling and re-use of water is now recognised as a key component in water resource management (Po, D. Kaercher & Nancarrow 2003). Along with the technological advances in wastewater treatment, the opportunity for water re-use has never been more viable. The following objectives and issues are key elements in developing strategic actions for the conservation and reuse of water resources.

3.4.1 Water Consumption Assessment

This strategic objective focuses on water consumption assessment. The assessment targets water conservation programs and highlights the importance of understanding how water is used locally and nationally. An important consideration is to understand and identify where and what are the principle water supply sources of the region. The water consumption assessment should involve the collation of information pertaining to water usage in regards to a supply and demand water balance.

The water balance needs to identify the main water consumption areas and recognise cost-effective opportunities to save water through a cost savings/benefit analyses (Seneviratne 2007). Figure 24 shows that in 2004-5 surface water was our main source of water supply providing 96 per cent of our total consumption, groundwater contributed 3.9 per cent and the remainder 0.1 per cent was sourced from desalinated water.

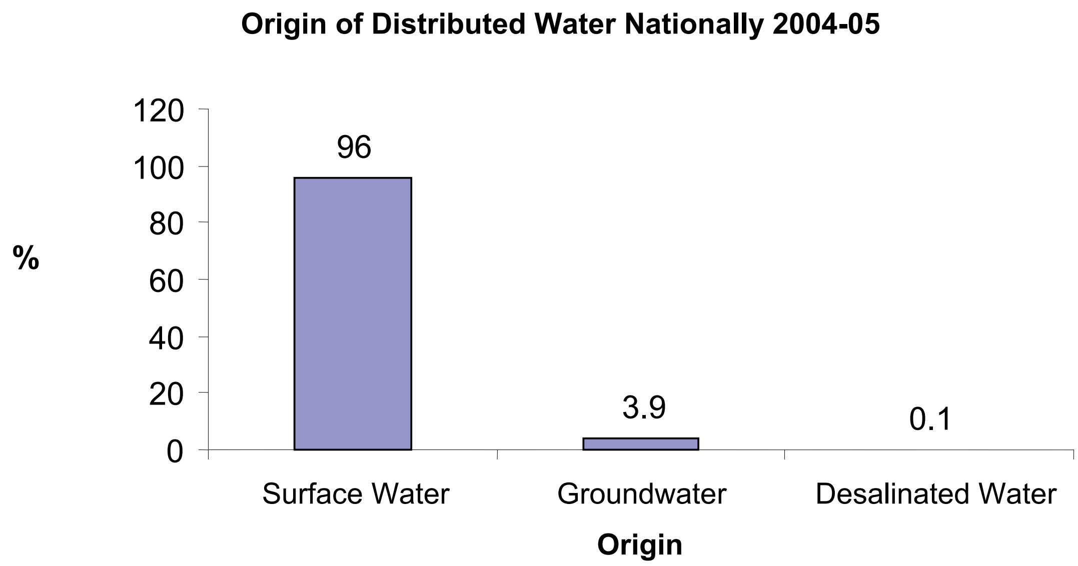


Figure 24: The national origins of distributed water for 2004-05 (Source : 'Australian Bureau of Statistics - Water Account Australia 2004-05' 2006).

Nationally in Australia 16 percent of fresh water is used for households, 18 per cent is lost in distribution and 47 percent is used by Agriculture which is the highest consumer. The remainder 19 per cent of fresh water is distributed to mining, forestry and manufacturing. Outside uses vary considerably between 30-70 per cent due to climatic conditions, urban density and geological characteristics ('Australian Bureau of Statistics - Water Account Australia 2004-05' 2006). Figure 25 depicts the national current water distribution by industry in Australia.

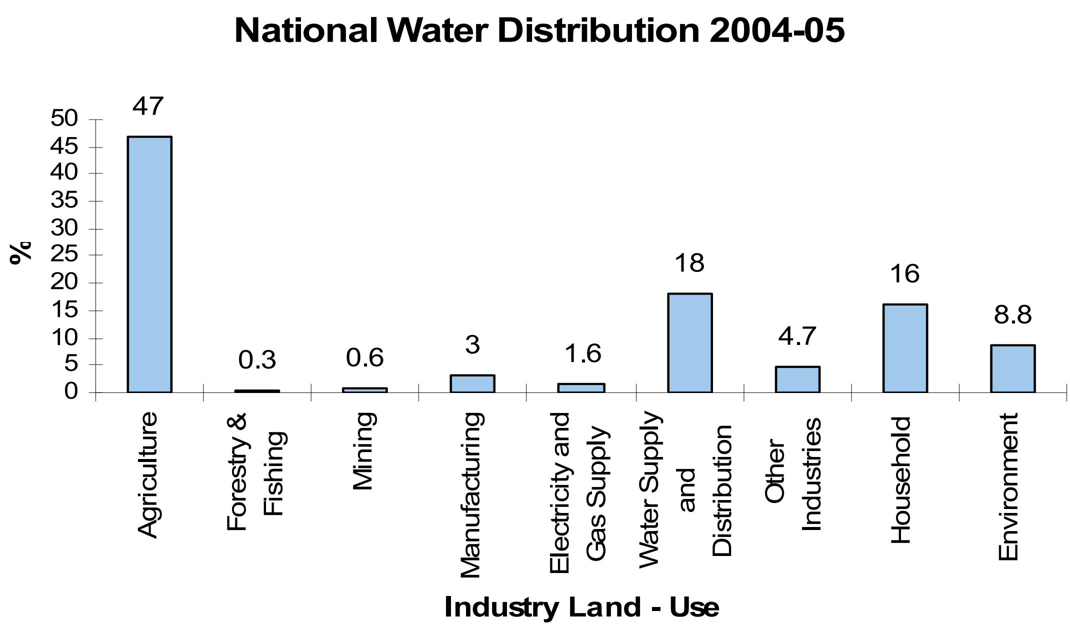


Figure 25: National distribution of water for 2004-05 in Australia (Source: 'Australian Bureau of Statistics - Water Account Australia 2004-05' 2006).

In the Sydney metropolitan area, household urban water demand accounts for approximately 70 percent of Sydney's total water consumption while commercial, industrial and distribution losses account for 30 percent of water consumption.

Figure 26 illustrates the use of potable water consumption within a household residence. It is interesting to note that approximately 41 percent of reticulated water in Sydney residences is used for lawn and gardening watering, toilets, swimming pools and car washing etc. where stormwater reuse/harvesting could be substituted for reticulated water (Roman & Philips 2007).

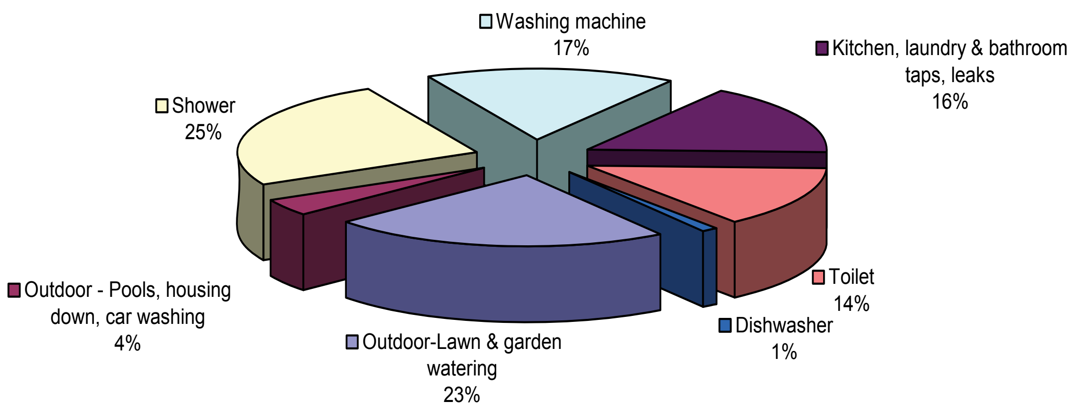


Figure 26: Average water consumption distribution for the Sydney Region (Source: Roman & Philips 2007).

The focus of this strategic objective is to develop actions that evaluate the water consumption demand of the local government area. The demand should achieve a balance between economic, social and environmental outcomes incorporating initiatives such as water efficiency practices and water conservation and reuse. Strategies to effectively assess the demand for water resources require an understanding of how and where water is used, an evaluation of the costs and benefits and the implementation of a demand management program.

3.4.2 Water Conservation Management Programs

This strategic element develops actions involving water conservation plans, water efficient fixtures, water efficiency audits, rebate programs, planning and water recycling/sewer mining programs.

As indicated above it is vitally important to understand how water is used before management plans can be formulated. International programs such as the "Water Campaign" developed by the International Council for Local Environmental Initiatives (ICLEI) assist local governments in their efforts to manage water conservation sustainably and effectively.

The Water Campaign provides a water management framework that encourages the development of local water action plans to achieve tangible improvements in water conservation. Participants in the campaign work towards achieving holistic integrated water resources management. This framework incorporates a water consumption inventory, reduction goals, water quality improvements and a action management plan (*Guidelines for Water Savings Action Plans* 2007).

In NSW, the State government initiatives included the Water Savings Action Plan (*Sydney Water Every Drop Counts Business Program* 2007) and "Every Drop Counts' program, developed by Sydney Water. These programs encourage local governments to evaluate water consumption through technical audits to determine how much water is currently used by Councils. The Plan identifies savings by carrying out water efficiency audits and analysing water consumption with the objective of minimising wastage and to develop sustainable solutions to reduce overall water consumption and improve operational water efficiency.

Local governments would need to establish partnerships with state and non government agencies to encourage innovation and to strengthen water conservation programs. By fostering partnerships and sharing water conservation responsibilities with stakeholders (i.e. agencies, industry, community and environmental groups) local governments can then be confident in using "best practice" to achieve goals and targets (Po, Kaercher & Nancarrow 2003). Important programs should include in-house education to promote water smart practices, water reuse and sewer management and community education in regards to water conservation and re-use.

3.4.3 Community Education, Attitudes and Barriers

This strategic element focuses on understanding the issues and barriers that affect the behavioural acceptability concerning the community using recycled water. Education and promoting knowledge exchange within the community and understanding of the perceptions of risk associated with using recycled water must first be examined to gain community confidence. Community education programs must identify and define uses and sources, instil trust and knowledge of the practices associated with re-use, and increase positive attitudes towards the benefits of water re-use (*Guidelines for Sewerage Systems - Use of Reclaimed Water* 2000; Po, D. Kaercher & Nancarrow 2003).

Industry and community engagement should be encouraged and partnerships established with local government in adopting water reuse strategies. An important consideration to advance this initiative is to review superfluous legislation and eliminate water reuse bureaucratic barriers. Such initiatives should encourage the wider community to take ownership of the local environment by de-regulating and eliminating barriers and educating sustainable management practices (i.e. in-house education, water smart practices and community education) to stakeholders in the use of water resources.

Barriers in water conservation and reuse can also be bureaucratic. Governments and authorities, politicians and high profile advisory committees should be encouraged to advance water reuse/recycled programs. National guidelines for water re-use should be developed to ensure a uniform national approach is applied to treatment, reuse and recycling of sewage effluent to eliminate conflicting State laws and inconsistent water reuse standards.

The National Water Quality Management Strategy was introduced as a joint Commonwealth/Sate/Territory initiative to achieve sustainable use of the nation’s water resources. The main guideline strategy that deals with aspects of water recycling is the “Guidelines for Sewerage Systems – Use of Reclaimed Water” (*Guidelines for Sewerage Systems - Use of Reclaimed Water* 2000).

The national guidelines currently only address recycled water from municipal sewage treatment plants. They do however consider a range of uses but are not sufficiently detailed to provide a nationally consistent approach to the treatment and recycling of sewage effluent. They are also not directly applicable to greywater or stormwater. Further, the NSW, Queensland and Victoria governments have developed their individual guidelines, which are inconsistent with each other.

The guidelines for the use of reclaimed water that apply in Victoria, NSW & Queensland are based on the National Water Quality Management Strategy (NWQMS) - Guidelines for Sewerage Systems – Reclaimed Water guidelines (*Guidelines for Sewerage Systems - Use of Reclaimed Water* 2000). The guidelines have strong linkages with international literature that concentrate on public health issues and are mainly concerned with microbiological aspects and nutrient control. The NSW guidelines have been superseded by the NWQMS Guidelines for Sewerage Systems – Reclaimed Water guidelines. Appendix A, shows an overview of the 'reclaimed water' guidelines which have been developed by Victoria, NSW and Queensland.

The *Guidelines for Sewerage Systems – Reclaimed Water* (2000) are based on the United States Environment Protection Agency guidelines model (*Pollution Control Manual for Urban Stormwater* 1989) which are equally based on the Californian model and knowledge gained from other American states. The other main contributor has been the World Health Organisation (WHO) studies based on epidemiological research (Anderson et al. 1993).

Both WHO and USEPA, models and the NSW Guidelines for Urban and Residential Use of Reclaimed Water have been considered and integrated in the development of the NWQMS Guidelines for Sewerage Systems – Reclaimed Water guidelines (2000).

3.5 Strategic Framework

3.5.1 Introduction

This section outlines the administrative framework of the Strategy. It explains the administrative function of the Water Cycle Steering Committee, its role with the local government hierarchy, the project objectives, priorities and estimated costs. It also explains the type of stakeholders (i.e. primary or supporting) roles and responsibilities involved for accomplishing the strategic actions.

An important component of the Strategy is the performance review. The review evaluates the effectiveness of the Strategy for achieving its objectives by developing key performance indicators (KPI). Key performance indicators focus on environmental values, management goals and project targets to gauge the overall performance of the Strategy. The key performance indicators are shown in Table 8.

The Generic Water Cycle Management Strategy is depicted in Table 9. Strategic themes, goals and actions of the Generic Water Cycle Management Strategy have been sourced from the findings of the literature review, case study and from the research. As a result best management practices have been formulated and integrated in the Generic Water Cycle Management Strategy.

Objectives, Actions and Priorities

The strategic actions were developed by defining the objectives and priorities to understand what issues needed to be addressed in order to achieve sustainable outcomes ('Chapter 5 Water Sensitive Urban Design' 1999; *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* 2000) . Project priorities have been determined based on previous project management experience, literature and logical sequencing of accomplishing the actions.

Cost estimates are based on historical information and project management experience, the project estimates are:

- **10k -100k;**
- **100k-250k and**
- **250k-2M.**

The priorities and cost of the actions are characterised in three groups high (1-3 years), medium (3-6 years) and low (6-10 years) directed at primary stakeholders as shown in Table 6. Time scales are indicative and may vary depending on the nature of the action (i.e. temporal and spatial cycles), complexity (i.e. biological, capital works) and budget constraints or priorities of the actions.

Table 6: Priorities and costs rating of the Generic Water Cycle Management Strategy.

Priority Rating	Priority (Years)
High	**1-3**
Medium	**3-6**
Low	**6-10**

Water Cycle Steering Committee

The Water Cycle Steering Committee (WCSC) would be responsible for administering the Water Cycle Management Strategy. The WCSC would be co-ordinated by local government and will include representatives from science, engineering, community, industry, research intuitions, state and federal agencies, local government elected representative/s and representatives from the environmental health, planning, engineering and community divisions of Council.

The WCSC would engage a Water Cycle Officer (WCO) to report on the progress of the Strategy and to prioritise the projects/actions timeline. Primary stakeholders assisted by the supporting stakeholders will be delicate with the responsible for expediting and achieving the actions.

In scientific or technical projects (i.e. water balance), sub-committees may be formed comprising of technical specialists to develop projects and formulate actions.

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The Strategy local government organisational hierarchy (Figure 27) recognises four main areas of responsibility, these include, environmental health, planning, engineering and community. Communication within the organisation is “two way” allowing for ideas and concepts to be passed down and for feedback to be received in regards to the progress of the actions and outcomes of the projects. The organisation hierarchy is depicted in Figure 27.

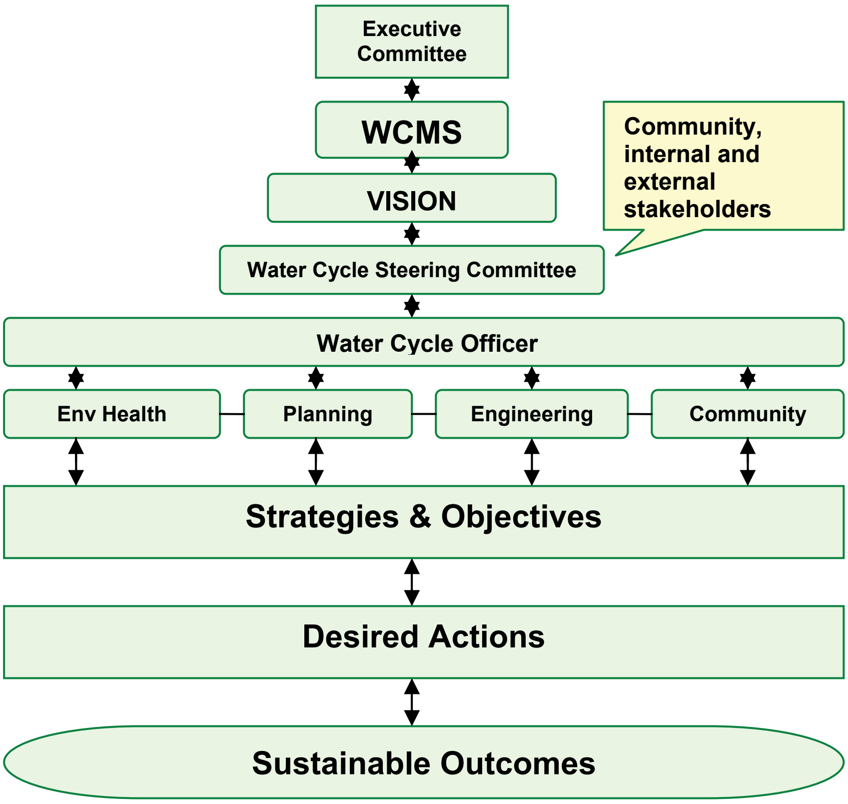

Figure 27: Divisional framework of the water cycle strategy.

The main agenda of the Water Cycle Steering Committee is to ensure that:

- management is issue driven;
- a pro-active approach is applied and not reactive;
- emphasis is on learning by doing;
- stakeholder partnerships are encouraged with a common goal;
- collation and access to information, knowledge and decision-making tools to promote collective learning; and
- a collaborative processes is applied to monitor, evaluate, report and revise on the water cycle in the local area.

Table 7 details the type of external stakeholders with there specific interests and responsibilities that would be involved in supporting actions of the Water Cycle Management Strategy.

Table 7: External stakeholders and the area of responsibility.

Stakeholder Type	Responsibility or interest
Property owners	Adjacent to watercourses, groundwater extraction and DA applicants.
Environmental Groups	Estuary, bushland, water quality, wetlands, waterways and threatened habitats.
Industry	Developers, mining, agriculture, manufacturing, commercial and retail industries.
Water Utilities	Wastewater treatment, water flows, water quality and stormwater.
Natural Resource Authorities	Protection of biota, habitat, natural communities and the balance and equitable use of natural resources.
Environmental Protection Authorities	The protection and designation of environmental values and uses, water quality targets, licensing of discharges and pollution prevention.
Planning Authorities	Land use regulation, control of land users, urban form and designated land use.
Research Institutions	Academic research in engineering, modelling, ecology and water cycle applied sciences.
Regional Groundwater Management Committee	Development and management of groundwater resources at a regional level.

3.5.2 Performance Review

The performance of the Strategy would need to be measured against realistic environmental values, management goals and targets. This may involve spatial and temporal evaluation of the objectives to ensure the effectiveness of the Strategy. Independent review of the Strategy and community expectation surveys will determine the effectiveness of the goals and actions.

Key performance indicators (Table 8) in activities such as predictive modelling, triple bottom line reporting (CRC *The Coastal CRC - NRM Information for Local Governments* 2006), water quality, water cycle balance, stream flows, ecological health, water usage, water conservation and social and economic indicators will gauge the performance of the Strategy. The key performance indicators (KPI's) are shown in Table 8.

Table 8 details the key performance indicators that may be used to gauge and determine the performance of the Water Cycle Management Strategy.

Table 8: Key performance indicators of the Water Cycle Management Strategy.

Key Performance Indicators – Water Cycle Management Strategy	
Objective	**Indicator**
Water balance sustainability	▪ Water balance assessments of impacted catchments v's pristine catchments. ▪ Groundwater resource levels. ▪ Healthy and sustainable biodiversity.
Conservation and enhancement of ecological health.	▪ Legislative, standards and nationally recognised/guidelines trigger levels. ▪ Accedence of pollutant loadings to aquatic environments from stormwater and wastewater outlets. ▪ Biological monitoring of significant habitats (i.e. fish, mammals, macroinvertebrates, diatoms) with narrow and specific tolerances. ▪ Remote sensing and GIS assessments.
Sustainable stream flows	▪ Pre European stream flow levels. ▪ Ratio of groundwater abstraction to groundwater recharge. ▪ River discontinuity. ▪ Catchments with dams and water retention devices v's catchments with no dams/retention.
Water quality in the environment	▪ The frequency of eutrophication (i.e. algal blooms). ▪ Accedence of water quality guidelines/standards. ▪ Evaluation of gaps in guidelines.
Water quantity in the environment.	▪ The volume of water derived from groundwater, surface water and reclaimed water resources. ▪ Frequency and duration of water shortages and droughts.
Water usage of the Local Government Area.	▪ Historical water usage by LGA sector. ▪ Land use water consumption patterns (i.e. residential, industrial, commercial and agriculture and environmental) ▪ Groundwater abstraction v's actual licence abstraction.
Water conservation and re-use	▪ Proportion of greywater, stormwater and blackwater recycled / reused. ▪ Proportion of wastewater reused before and after treatment. ▪ The amount of community reuse programs. ▪ Development applications that apply water conservation devices.
Social and economic	▪ Loss of recreational resources. ▪ Market and economic depression. ▪ Industry increase/decreases. ▪ Land sales demand and market valuations. ▪ Development applications. ▪ LGA population.

The Generic Water Cycle Management Strategy is the culmination of the findings from the literature review, case study and ideologies based on factual science and best management practices in water cycle management. The Generic Water Cycle Management Strategy is presented in Table 9.

Table 9: Generic Water Cycle Management Strategy for Local Government

3.2 Assessment of the Water Cycle

3.2.1 Water Balance

Objective	Action	Responsibility	Support	Cost $	Priority (Years)
WB1: Establish a Water Cycle Technical Committee to assess the water cycle balance of the local government area.	Implement research to determine the local and regional water cycle balance (i.e. seasonal and annual fluxes of rainfall, stream flow, evapo-transpiration, soil moisture, land use, vertical drainage and groundwater storage).	**Water Cycle Steering Committee**	**Bureau of Meteorology Research Institutions Planning Engineering**	**250k-2M**	**1-3**
WB2: Monitor rainfall of the LGA region.	Implement a rainfall monitoring program or source rainfall data in collaboration with state authorities, Bureau of Meteorology (BOM) to understand the precipitation inflow of the water balance.			**100k-250k**	**3-6**
WB3: Develop an understanding of water flow through the environment	Undertake scoping studies to understand the movement of water from the atmosphere through the catchments and how water interacts within natural and urban environments.		**BOM Research Institutions**	**10k-100k**	**1-3**
	Assess the infiltration, overflow, subsurface and ground flow characteristics and capabilities of the catchments.		**Research Institutions Env Health Planning**	**100k-250k**	**1-3**
WB4: Understand the water cycle interception effects in regards to land use.	Assess the different land-use impacts on the water cycle balance and determine evapo-transpiration effects/rates from land-use (i.e. rural, residential, commercial, bushland), and establish sustainable performance indicators.			**10k-100k**	**3-6**
WB5: Understand the significance of evaporation processes from the effects of land-use modifications.	Develop and Implement monitoring techniques to determine the evapo-transpiration of natural landscapes and the effects of evapo-transpiration on the water balance.			**10k-100k**	**1-3**
	Research and monitor evapo-transpiration for different land-use areas (i.e. urban, commercial, rural, bushland and waterways)			**10k-100k**	**1-3**
WB6: Undertake evapo-transpiration measurements of bushland and develop leaf area index rates.	Understand the effects of land-use modifications by measuring evapo-transpiration and leaf area index rates from terrestrial vegetation canopies to determine changes in groundwater availability, vegetative health and water balance changes.			**10k-100k**	**1-3**

3.2.1 Water Balance

Objective	Action	Responsibility	Support	Cost $	Priority (Years)
WB7: Develop an understanding of local groundwater resources.	Undertake a study to establish geological regions of groundwater occurrences and to determine areas of high, medium and low risk of over-extraction of groundwater resources.	**Env Health** **State Authorities**	**Engineering** **Planning**	**250k-2M**	**1-3**
	Establish techniques and protocols for groundwater exploration and management.			**10k-100k**	**3-6**
	Prepare a report on the development potential of groundwater storage.			**100k-250k**	**3-6**
	Using a risk assessment framework apply the precautionary principle to the management of groundwater resources through the development of a groundwater management strategy.			**10k-100k**	**3-6**
	Communicate groundwater status to the community annually.		**Community**	**10k-100k**	**3-6**
	Investigate groundwater flows to creeks and identify where the main discharges occur.		**Engineering** **Planning**	**100k-250k**	**3-6**
WB8: Understand the processes of groundwater dependent ecosystems.	Identify the significance of and map groundwater dependent ecosystems.			**250k-2M**	**1-3**
	Establish a management standard for groundwater resources that acknowledges the importance, conservation and protection of groundwater dependant ecosystems.			**100k-250k**	**3-6**
WB9: Keep abreast of current water cycle strategic research.	Review and critique current best practice and innovations in strategic water cycle management.	**Water Cycle Steering Committee**	**Env Health** **Planning** **Engineering**	**10k-100k**	**6-10**
WB10: Develop and apply water balance key performance indicators.	Determine the performance of the water balance strategy by modelling pre-European water balance levels to ascertain a level of acceptability for the urban water balance.			**10k-100k**	**1-3**
	Undertake a comparative assessment of the water balance of an impacted local region v's an unimpacted region.			**10k-100k**	**3-6**

3.2.2 Water Quality

Objective	Action	Responsibility	Support	Cost $	Priority (Years)
WQ1: Design a water quality monitoring program.	Prepare a water quality monitoring preliminary assessment to identify the scale and time period of the water quality study and the resources required (e.g. budget, time, expertise and equipment).	**Env Health**	**Planning** **Water Cycle Steering Committee** **Catchment Authorities** **Estuary Management Committee** **Planning** **Council Affiliations**	**10k-100k**	**1-3**
	Assess and identify resource limitations that may significantly alter the design and ability to address the objectives.			**10k-100k**	**1-3**
	Incorporate a quality control protocol to ensure integrity of the monitoring data (e.g. replicate samples, calibration, method audits and records keeping).			**10k-100k**	**1-3**
WQ2: Implement a water quality monitoring program for surface waters.	Monitor the presence and absence of a water quality condition in order to test whether the condition has an effect on the water cycle environment.			**10k-100k**	**3-6**
	Evaluate the size of the study area and apply statistical analysis to identify point and diffuse pollution sources.			**10k-100k**	**3-6**
	Monitor and compare results to water quality trigger values that are consistent with the national legislative standards and recognised water quality guidelines (ANZECC (2000c).	**Env Health**	**Council Affiliations** **Catchment Authorities** **Community**	**10k-100k**	**1-3**
	Measure cumulative catchment impacts on water quality and identify point sources.			**10k-100k**	**3-6**
	Develop benchmark water quality KPI's using pristine catchment regions, historical data, catchment characteristics, accedence of pollution loadings, frequency of algal events, community values and legislative standards , guidelines, remote sensing and GIS.			**100k-250k**	**3-6**
	Develop and compare ecosystem reference sites, using biological indicators (fish, mammals, macroinvertebrates, diatoms etc..), parameter concentrations and loads to provide a basis from which local comparisons with 'impacted' waterways can be made.		**Catchment Authorities** **Estuary Management Committee** **Planning**	**100k-250k**	**1-3**

3.2.2 Water Quality (cont'd)

Objective	Action	Responsibility	Support	Cost $	Priority (Years)
WQ3: Promote the results of the surface water quality monitoring program.	Consult with State Authorities to review biodiversity stress indicators in regards to the water monitoring of sensitive habitats.	**Env Health**	**State Authorities**	**10k-100k**	**3-6**
	Evaluate the water quality monitoring program biannually in consultation with neighbouring and affiliated Councils and research institutions.		**Research Institutions** **Council Affiliations**		
	Report on the water quality condition to the community, state and federal authorities (i.e. State of Environment Reporting).		**Community State/ Federal Gov**		
WQ4: Design a groundwater quality assessment program.	Review literature on the local and regional geology and hydrogeology to identify unconfined/confined groundwater.		**Planning** **Water Cycle Steering Committee** **Engineering**	**10k-100k**	**1-3**
	Undertake investigations to identify aquifers and confining layers, water table, lateral and vertical hydraulic gradients, flow velocity, source of recharge and discharge outlets of groundwater.			**250k-2M**	**3-6**
	Identify potential, current and future water users, water bodies and groundwater ecosystems.	**Env Health** **Community**		**10k-100k**	**3-6**
	Incorporate physical, chemical and biological indicators of the groundwater quality assessment.	**Env Health**	**Water Cycle Steering Committee** **Research Institutions** **Engineering**	**100k-250k**	**3-6**
WQ5: Implement a groundwater quality assessment program.	Monitor natural background groundwater quality to distinguish between naturally occurring concentrations of anthropogenic contamination and compare results against national guidelines (i.e. ANZECC) for the protection of groundwater resources.			**250k-2M**	**1-3**
WQ6: Understand urban impacts on groundwater resources.	Understand the spatial and temporal boundaries of groundwater resources and the water demands and needs of the community.	**Community** **Env Health**	**Env Health** **Engineering** **Planning**	**10k-100k**	**3-6**
	Research the historical exposure to toxic chemicals, wastewaters, irrigation and extraction impacts that have the potential for groundwater contamination.		**Planning** **State Authorities**	**100k-250k**	**1-3**

3.2.3 Stream Flows

Objective	Action	Responsibility	Support	Cost $	Priority (Years)
SF1: Understand the functionality of streams, catchment hydrology and stream flow patterns.	Monitor and assess annual, seasonal and daily flow patterns to determine the physical and biological properties of surface flows.	**Env Health**	**Water Cycle Technical Committee Research Institutions State Authorities**	**100k-250k**	**3-6**
	Collect data and apply statistical analysis to reveal differences in stream flows between catchments and changes attributed to land-use modifications.				
	Work in partnership with Council engineers to understand catchment hydrology and land capability of stream flows.	**Env Health Planning Engineering**		**10k-100k**	**3-6**
	Undertake preliminary assessments of stream flows to determine average volumes, seasonal distribution variability and trends through time.			**10k-100k**	**1-3**
	Investigate rainfall lost from the catchment and determine the proportion of rainfall driving stream flows during low, medium and high intensity rainfall events.			**10k-100k**	**1-3**
	Interpret trends over time in stream flows and habitat changes.			**10k-100k**	**3-6**
SF2: Understanding the effects of urbanisation and development impacts on stream flows.	Undertake an assessment of diminishing stream flows from the effects of dams, reservoirs, artificial wetlands, rainwater tanks etc.			**250k-2M**	**1-3**
	Assess river sediment load depositions in floodplains, aquatic habitats and deltas from the effects of dams, reservoirs and artificial wetlands.			**250k-2M**	**3-6**
SF3: Research and develop key performance indicators to understand the variability of stream flows.	Develop stream flow biological indicators (i.e. microinvertertebrates, diatoms, and macrofauna) that are influenced by the intensity of the flow regime to determine the variability of stream flows.			**250k-2M**	**1-3**
	Undertake modelling assessments to determine baseline and pre European indicator flow levels and compare regions with river obstructions, dams/retention to unimpacted regions.	**Env Health**		**10k-100k**	**3-6**

3.2.4 Ecosystem Health

Objective	Action	Responsibility	Support	Cost $	Priority (Years)
EH1: Understand the ecological processes of the water cycle to ensure sustainable management of ecosystem health by applying "best practice" methodologies.	Identify potential impacts to ensure ecosystems environmental integrity.	**Env Health Estuary Management Committee**	**Water Cycle Steering Research Institutions Planning State Authorities**	**10k-100k**	**1-3**
	Assess the short term variability associated with seasonal change of habitats and species interrelated with the water cycle to gain an understanding of the current condition of streams, rivers, wetlands, estuaries and groundwater dependent ecosystems.			**250k-2M**	**3-6**
EH2: Assess the condition of ecosystem health by researching the biophysical processes and functions of surface ecosystems to support informed decisions on ecosystem management.	Research current and future studies and programs to define baseline conditions of the various ecosystem processes and the interactions between physical, chemical and biological processes.			**100k-250k**	**3-6**
	Research biota and assess the short term variability associated with seasonal change of the water cycle.			**10k-100k**	**3-6**
	Identify streams, wetlands, intertidal/riparian zone vegetation, seagrasses, mangroves and saltmarsh communities.			**10k-100k**	**3-6**
	Identify and list aquatic and terrestrial riparian threatened species, populations, ecological communities and critical habitat that may be present in the locality.			**10k-100k**	**6-10**
	Identify finfish and macro-invertebrate species and assess the migration and distribution, reproductive patterns, recreational and commercial catch size and review aquaculture impacts and assess the relationship between water quality and stream flow variability.			**10k-100k**	**3-6**
	Research and assess the expected change in biodiversity caused by increases in development.			**100k-250k**	**1-3**
	Develop and apply biological indicators correlated with local conditions to assess ecosystem health.			**10k-100k**	**1-3**
	Apply real time data collection to determine and predict future occurrences of algal blooms.			**10k-100k**	**3-6**

3.2.4 Ecosystem Health (cont'd)

Objective	Action	Responsibility	Support	Cost $	Priority (Years)
EH3: Evaluate and identify the vulnerability and environmental values of groundwater dependent ecosystems (GDE's.	Research and review existing vulnerability maps or create vulnerability maps to identify groundwater dependent ecosystem locations.	**Env Health Planning**	**State Authorities Water Cycle Steering Committee**	**10k-100k**	**3-6**
	Work in partnership with neighbouring Councils and state authorities to list known location and type of groundwater dependent ecosystem (i.e. wetlands, base flows, aquifer, cave ecosystems),			**10k-100k**	**3-6**
	Assess the vulnerability of groundwater dependent ecosystems (GDE's) by developing vulnerability maps to assess the vulnerability from over-extraction and contamination.			**10k-100k**	**3-6**
	Implement monitoring techniques and develop indicators to assess the tolerance of GDE's to water quality "pulse" variations.			**100k-250k**	**3-6**
	Prioritise the value of GDE's by assessing the uniqueness of the ecosystem and the benefits GDE's bring to the community.			**100k-250k**	**3-6**
	Identify gaps in information and apply the precautionary principle to minimise the impact on GDE's.			**100k-250k**	**1-3**
EH4: Define and assess sedimentary impacts on ecosystem health from urbanisation.	Evaluate sediment movement, sedimentation rates, and sediment toxicity types impacts on benthic infauna, through contamination (e.g. heavy metals and organochlorines) and from remobilisation of sediments and hydrodynamic impact processes.	**Env Health**	**Planning Engineering Water Cycle Steering Committee**	**100k-250k**	**3-6**
	Investigate hydrodynamic changes such as surface flow regime, tidal behaviour and freshwater inputs that are likely to effect ecosystem health and as a result the water cycle.			**100k-250k**	**3-6**
EH5: Gauge the performance of the methodologies used to assess ecosystem health.	Undertake a performance review of the effectiveness of ecosystem health assessments every five years to rate ecosystem health and the performance of the ecological health assessments.			**10k-100k**	**3-6**

3.2.5 Catchment Modelling and GIS

Objective	Action	Responsibility	Support	Cost $	Priority (Years)
CM1: Develop and apply predictive catchment modelling to simulate the water cycle, catchment hydrology and urban water use.	Research modelling applications that are highly regarded within the industry that may be applied to address issues and suitability to answer environmental issues/questions.	**Env Health** **Planning** **Engineering**	**Water Cycle Steering Committee** **Research Institutions (CRC. Ewater)** **Federal and State Authorities**	**100k-250k**	**1-3**
	Undertake and review modelling applications to fully understand the modelling requirements, in regards to design, construction and selection of available modelling tools.			**10k-100k**	**1-3**
	Research and prioritise key questions and issues in relation to water balance, stream flows, water quality/quantity and ecosystem health.			**100k-250k**	**3-6**
	Identify and apply modelling applications with clear realistic performance targets.			**10k-100k**	**3-6**
	Develop, apply and integrate modelling for catchment and urban use to simulate and predict the effects of urban impacts on the water cycle.			**250k-2M**	**1-3**
	Develop and implement predictive modelling to evaluate the local water balance.			**250k-2M**	**6-10**
	Undertake model calibration on a spatial and temporal scale supported by field data to ensure the integrity and quality of the model outputs.			**10k-100k**	**1-3**
	Develop and apply model sensitivity analysis as part of the calibration process to examine the model response.			**10k-100k**	**1-3**
	Undertake an audit of the model processes to examine whether the model is producing useful outputs that reflect an accurate representation of reality e.g. environment.			**10k-100k**	**3-6**

3.2.5 Catchment Modelling and GIS (cont'd)

Objective	Action	Responsibility	Support	Cost $	Priority (Years)
CM2: Install and integrate GIS with hydrological modelling to simulate the causes and effects of land use.	Model the spatial analysis of rainfall and the physical elements of the water cycle by using a three dimensional depiction of the catchment morphology encompassing the shape of land, surface terrain, catchment, stream flow and characteristics of the landscapes.	**Env Health** **Planning** **Engineering**	**Water Cycle Steering Committee** **Research Institutions (CRC. Ewater)** **Federal and State Authorities**	**100k-250k**	**3-6**
	Apply GIS and water cycle modelling to simulate and synthesise the manner and speed of water in the atmosphere, in surface water and in groundwater to examine prediction scenarios for single issues such as stream flows, groundwater and aquifer recharge.			**100k-250k**	**3-6**
CM3: Apply predictive modelling to strategic planning to aid a decision support system by which land use decisions can be assessed.	Integrate modelling frameworks to GIS formats specifically designed to simulate holistic water cycle responses to land use change and climate variability.	**Engineering** **Env Health** **Planning**	**Water Cycle Steering Committee**	**100k-250k**	**1-3**
	Model environmental flows pre European settlement to determine baseline flow targets.			**10k-100k**	**6-10**
CM4: Evaluate and manage the impacts of development on the water cycle.	Collaborate with Planning and Engineering Divisions and develop hydrological, ecological and end use modelling capabilities to evaluate the water balance implications for future planning developments.			**100k-250k**	**1-3**
	Apply modelling to determine the implications of damming/ water capture, (e.g. household water tanks) on environmental flows and local ecology.			**10k-100k**	**3-6**
	Apply predictive modelling to assess and review environmental planning and town planning instruments and to minimise impacts on the water cycle.				
	Apply catchment modelling and compare with reference data to understand and manage the implications of current and future development on the water cycle.	**Env Health**	**Estuary Management Committee** **Water Cycle Steering Committee**	**100k-250k**	**1-3**

3.2.5 Catchment Modelling and GIS (cont'd)

Objective	Action	Responsibility	Support	Cost $	Priority (Years)
CM5: Evaluate the water balance demand against the availability of water resources for current and future needs.	Develop and apply predictive hydrological modelling to assess current water demand and identify key issues and trends in water consumption, conservation, environmental flows, groundwater management, inter-catchment transfers, source substitution, sewage treatment plant flows, stormwater flows and reuse.	**Env Health**	**Planning** **Water Cycle Steering Committee**	**10k-100k**	**1-3**
CM6: Evaluate stormwater runoff quality.	Evaluate the water quality of urban and non urban areas.	**Env Health**	**Engineering** **Planning**	**10k-100k**	**1-3**
CM7: Evaluate water quality treatment processes.	Evaluate the performance of stormwater treatment devices such as gross pollutant traps , trash racks and wetlands.			**10k-100k**	
CM8: Evaluate the effects of population increases.	Develop and apply modelling scenarios to predict the carrying capacity of population increases on the water cycle environment.	**Planning**	**Water Cycle Steering Committee**	**100k-250k**	**1-3**
CM9: Develop and apply modelling to understand the effects of climate change on the water cycle.	Monitor climatic temperature trends on a local scale in association with research authorities.	**Env Health**	**BOM** **State Authorities** **Research Institutions**	**10k-100k**	**6-10**
	Undertake desktop modelling to investigate potential climate change impacts on the water cycle such as sea level rise, temperature, wind, storms, and groundwater levels.			**10k-100k**	**3-6**

3.3 Manage Human Induced Impacts on the Water Cycle

3.3.1 Planning, Governance and Community Education

Objective	Action	Responsibility	Support	Cost $	Priority (Years)
PG1: Promote and integrate the Water Cycle Management Strategy with Council's planning regulations, community and external stakeholders.	Intergrate water cycle strategy methods, practices and policies with local government planning regulative instruments (i.e. LEP's, DCP's, Agenda 21,SMP, CMP). Direct and advise strategic planning to prioritise masterplans and project areas for future water cycle related planning projects.	**Planning**	**Water Cycle Steering Committee** **Community**	**10k-100k**	**6-10**
PG2: Instil confidence within Planning and Management and community stakeholders in regards to the Water Cycle Management Strategy.	Ensure water cycle planning processes are transparent and rigorous to ensure resources are being spent in the most cost effective and appropriate means.	**Community**	**Water Cycle Steering Committee**	**10k-100k**	**3-6**
PG3: Introduce a water cycle environmental levy to support the objectives and actions of the Water Cycle Management Strategy.	Develop a water cycle remediation program to treat and remediate human induced impacts on the water cycle (i.e. water quality, surface ecosystems, groundwater, groundwater dependent ecosystems, stream flows and climate change). Monitor actions and develop water balance and catchment modelling to identify priorities and cost effectiveness of the actions. Implement a capital costs and charges plan to budget for water cycle capital works.	**Env Heath** **Engineering**	**Community** **Water Cycle Steering Committee**	**250k-2M**	**1-3**
PG4: Ensure the objectives of the Water Cycle Management Strategy are integrated with the development assessment process.	Introduce guidelines and training procedures within the development assessment process that include the values and concepts of the Water Cycle Management Strategy.	**Planning**	**Env Health**	**10k-100k**	**3-6**
PG5: Develop and implement key performance indicators to assess the effectiveness of the Water Cycle Management Strategy.	Develop and review annually KPI's incorporating social, environmental and economic values. Review the WCMS every 5 years and re-assess the achievements and effectiveness of the actions.	**Water Cycle Steering Committee**	**Env Health** **Planning Engineering**	**10k-100k**	**3-6**

3.3.1 Planning, Governance and Community Education

Objective	Action	Responsibility	Support	Cost $	Priority
PG6: Build partnerships with Federal, State and Local Government jurisdictions to develop long term research opportunities.	Source grant funding and form partnerships for water cycle related research in association with authorities, universities and industry.	**Water Cycle Steering Committee (WCSC)**	**Research Institutions** **Federal & State Natural Resources Authorities** **Community**	**100k-250k**	**High**
	Establish and maintain partnerships with key stakeholders to improve the efficiency, quality and value of water cycle related projects.			**10k-100k**	**Medium**
PG7: Foster research and advance innovation in water cycle management.	Engage the community/stakeholders by contributing cash and in-kind resources for worthwhile scientific projects recognised in the Water Cycle Management Strategy.			**10k-100k**	**Low**
PG8: Promote research sharing and innovation for managing human induced impacts on the water cycle.	Participate in national and international conferences and represent local government at respected research and environmental management committees.	**Env Health**	**WCSC** **Engineering**	**100k-250k**	**Medium**
PG9: Facilitate training to remediate anthropogenic impacts on the water cycle.	Provide training courses, technical training and educational materials (e.g. fact sheets and guidelines) and implement education campaigns to remediate the impacts of urbanisation.	**Env Health** **Planning** **Engineering**	**WCSC** **Community** **Env Health** **Env Protection Authorities** **Catchment Management Authorities**	**10k-100k**	**High**
	Develop training programs such as fact sheets on litter, building site erosion, swimming pool discharges, industrial practices policies and environmental legislative requirements targeted at the private sector and local government.			**10k-100k**	
PG10: Improve governance of the Ecological Sustainable Development assessment and enforcement processes to minimise the effects of urbanisation.	Provide local government staff and developers with appropriate water quality objectives and pragmatic ESD (Agenda 21) guidelines on how to apply them.	**Planning**		**10k-100k**	**High**
	Apply judiciously the use of enforcement powers (e.g. on the spot fines) and provide training for technical solutions to common problems and improve guidelines, standards and reward innovative responsible developers.			**10k-100k**	

3.3.1 Planning, Governance and Community Education (cont'd)

Objective	Action	Responsibility	Support	Cost $	Priority
PG11: Incorporate and enhance water cycle management values through strategic catchment planning.	Promote and encourage community ownership of catchment planning practices to ensure water cycle values are accepted and incorporated within all planning and ESD instruments (i.e. LEP, DCP'S, Agenda 21,TBL)	**Planning**	**Planning and Natural Resources Authorities** **Catchment Management Authorities** **Env Health**	**10k-100k**	**High**
	Research and refine processes to identify appropriate land-use locations for future planning studies and water cycle management.			**10K-100k**	**Medium**
	Ensure planning controls are transparent and are performance based and rigorous to ensure resources are used cost effectively and in the appropriate locations.			**10k-100k**	**High**
	Ensure environmental and planning controls are unambiguous and have consistent outcomes and values.			**10k-100k**	**High**
	Research and develop water cycle balance modelling in urbanised areas to ensure ecologically sustainable development in regards to population increases.	**Engineering** **Env Health**	**Water Cycle Steering Committee** **Planning**	**100k-250k**	**Medium**
	Engage and establish partnerships with community stakeholders to support and promote water cycle related issues within corporate and planning forums (e.g. grants, awards, stencilling, posters, displays, training, etc.)	**Community** **Planning**	**Planning and Natural Resources Authorities**	**10k-100k**	**Medium**
	Develop and implement a planning strategy to maximise water cycle priorities within the development assessment process.			**10k-100k**	**High**
	Encourage and promote business incentives to support the values and actions of the Water Cycle Management Strategy.			**10k-100k**	**Medium**

3.3.2 Apply Water Sensitive Urban Design

Objective	Action	Responsibility	Support	Cost $	Priority (Years)
UD1: Develop and apply urban design protocols to minimise the impact on the water cycle from new developments.	Analyse the catchment and identify natural features to be preserved including topography, drainage patterns, soils, geology, groundcover and sensitive regions (i.e. wetlands, waterways, remnant vegetation and wildlife corridors).	**Planning**	**Env Health**	**10k-100k**	**3-6**
	Undertake an assessment of stormwater and drainage requirements and the potential impact on natural waterway.	**Engineering Water Cycle Steering Committee**	**Env Health**	**10k-100k**	**1-3**
	Maintain stormwater management structures and stormwater treatment devices.	**Engineering Water Cycle Steering Committee**	**Env Health**	**10k-100k**	**1-3**
UD2: Assess land ecological "foot print" capability to sustain specific land use.	Apply modelling (i.e. water quality, population densities) to identify the ecological footprint and physical capability of the site, region and catchment.	**Engineering Water Cycle Steering Committee**	**Env Health Planning**	**10k-100k**	**3-6**
	Research and identify case studies that have similar attributes of the LGA under development to gain an understanding of potential future impacts.	**Engineering Water Cycle Steering Committee**	**Env Health Planning**	**10k-100k**	**3-6**
	Identify and protect areas of environmental significance and determine where development should occur to produce the minimal impact on the water cycle environment.	**Env Health**	**Natural Resource Authorities Planning**	**10k-100k**	**1-3**
UD3: Identify and apply cost effective "soft" ecological practices to minimise impacts from new development on the water cycle.	Ensure development design incorporates effective site planning that will minimise site disturbance, avoid increased demand on stream flows and remove water-born pollution to receiving waters.	**Env Health**	**Natural Resource Authorities Planning**	**100k-250k**	**3-6**
	Incorporate the application of surface water and groundwater treatment measures such as wetlands, sediment traps and infiltration/ retention on new developments.	**Env Health**	**Natural Resource Authorities Planning**	**100k-250k**	**3-6**
	Manage water locally by detaining surface water locally in consideration of soils and topography and ensure that pollution mobilisation and conveyance within and from the site are minimised.	**Env Health**	**Natural Resource Authorities Planning**	**100k-250k**	**3-6**
	Promote community participation and education by increasing public amenities through landscaping of wetlands and wildlife corridor habitats.	**Env Health**	**Natural Resource Authorities Planning**	**100k-250k**	**3-6**

3.3.2 Apply Water Sensitive Urban Design (cont'd)

Objective	Action	Responsibility	Support	Cost $	Priority
UD4: Apply and incorporate water sensitive urban design techniques to road and sub-division developments to minimise impacts on the water cycle.	Minimise impervious areas and formal drainage systems to encourage infiltration and stormwater re-use.	**Planning** **Env Health** **Engineering**	**Environmental Protection Authorities** **Environmental Planning Authorities**	**100k-250k**	**Medium**
	Encourage natural habitats (e.g. watercourses) and buffer areas adjacent to streams to promote habitat, stream flows and the natural assimilation of surface water pollution.			**10k-100k**	**High**
	Use grass swales in place of kerb and gutter within the roadways.			**10k-100k**	**High**
UD5: Promote and apply surface water infiltration at development sites.	Apply landscaping and infiltration swales, porous paving to aid infiltration of surface water prior to discharge.			**10k-100k**	**High**
	Apply upstream treatment porous zones such as grassed swales and vegetative filter strips to reduce the accumulation of pollution downstream.			**10k-100k**	**Medium**
	Reduce impermeable surface discharging directly to the drainage system and natural streams.			**100k-250k**	**Medium**
	Minimise traffic, sediment, and organic debris in porous zones to enhance infiltration performance.			**10k-100k**	**Medium**
UD6: Incorporate roadway planning and natural landscapes design to enhance stormwater infiltration, groundwater recharge and pollutant screening.	Incorporate natural landscapes such as native vegetative grasslands and promote the capture and infiltration of runoff through the use of depressions, swales, contour banks, rock channel, settling ponds and reed beds.			**100k-250k**	**Medium**
	Reduce water consumption and fertiliser application by promoting the use of native grasses and groundcover species that are favourable to low watering demands.			**250k-2M**	**Medium**

3.3.2 Apply Water Sensitive Urban Design (cont'd)

Objective	Objective	Responsibility	Support	Cost $	Priority
UD7: Integrate water cycle land use design concepts with town planning design criteria to maintain consistent water cycle values.	Ensure that the streetscape complements the natural topography of the catchment thus avoiding the need for major excavation and steep gradients, so as to reduce runoff volume and velocity.	**Planning** **Engineering** **Env Health**	**Env Health** **Environmental Protection Authorities** **Environmental Planning Authorities**	**10k-100k**	**Medium**
	Integrate pathways between community public open space with habitat and surface water corridors.				
UD8: Promote infiltration in new urban areas by reducing impervious surfaces for housing and roadway developments.	Encourage and lobby amendments to national planning and building codes to minimise the extent of paving by introducing shorter residential driveways.			**100k-250k**	**High**
	Provide street carriageway vegetated filter strips to convey stormwater, aid filtration and to ensure accommodation of vehicles, whilst providing dissipation, detention, infiltration and screening of surface water.			**100k-250k**	**Medium**
UD9: Increase landscape infiltration capabilities within the urban areas.	Design roadways and parking areas to filter surface flows by incorporate detention basins and directing excess surface flows by surface swale drains.			**100k-250k**	**Medium**
	Use porous pavements and infiltration trenches for parking areas that are used infrequently and incorporate gently sloping grassed areas or recessed basins into parking areas to detain and treat surface water.			**10k-100k**	**Medium**
	Direct minor flows to swales along the roadways and direct major flows along the roadway.			**100k-250k**	**Low**
	Incorporate underground power and telecommunications services to increase landscape infiltration opportunities.			**100k-250k**	**Low**
	Amend central commercial and business district and development control planning codes to incorporate roof gardens in high density developments.			**100k-250k**	**Medium**
UD10: Encourage innovative water sensitive urban design by rewarding architects, engineers, scientists and builders.	Establish local awards that reward creative, effective and practical landscape designs that promotes water cycle urban design.			**10k-100k**	**Medium**

3.3.2 Apply Water Sensitive Urban Design (cont'd)

Objective	Objective	Responsibility	Support	Cost $	Priority (Years)
UD11: Develop and implement a maintenance and rehabilitation program to ensure all water sensitive urban design concepts and technologies are performing effectively.	Develop a rehabilitation and maintenance plan to identify high priority areas for rehabilitation.	**Env Health**	**Engineering**	**250k-2M**	**1-3**
	Undertake routine monitoring, maintenance and rehabilitation of natural systems such as waterways, wetlands, rivers, riparian foreshore, lakes, estuaries and costal regions.			**10k-100k**	**1-3**
	Establish a maintenance, rehabilitation and performance evaluation program for water sensitive urban design devices (i.e. basins, control ponds, lakes, wetlands, bioretention swales, buffer strips, infiltration measures, sand filters etc.)			**100k-250k**	**3-6**
	Encourage community stakeholders to take ownership of environmental assets by maintaining and rehabilitating significant environmental areas. This imitative would include recognition awards and funding.	**Community**	**Planning** **Env Health** **Environmental Protection Authorities** **Environmental Planning Authorities**	**10k-100k**	**3-6**
	Regularly audit water sensitive urban design assets and review public health and liability risk assessments to ensure maintenance and functioning requirements are acceptable and satisfactory.	**Env Health**		**10k-100k**	**1-3**
	Develop ongoing ownership strategies in partnership with stakeholders to ensure maintenance and rehabilitation practices are continually improved.				
	Maintain flood mitigation schemes and undertake drainage rehabilitation work to replace assets that have failed.	**Engineering**		**100k-250k**	**1-3**
	Establish an asset management register to prioritise and value water sensitive urban design assets and to improve maintenance scheduling.			**10k-100k**	**1-3**
	Undertake benchmarking, research and development assessment to ensure that new asset designs and maintenance practices are recognised as "best practice".	**Env Health** **Research Institutions** **Engineering**		**250k-2M**	**1-3**
UD12: Assess and report on the performance of the water sensitive urban design initiatives.	Undertake studies and modelling to determine the effectiveness of water sensitive urban design methods (i.e. water quality, soil infiltration, stream flow and groundwater recharge).			**10k-100k**	**1-3**

3.3.3 Protect and Enhance Urban Surface Water Quality

Objective	Action	Responsibility	Support	Cost $	Priority
PW1: Minimise and control point and diffuse source pollution from proposed or pre-existing developments.	Apply erosion and sediment mitigation controls (i.e. Soil and Water Management Plan) to screen, capture and protect surface waters and downstream aquatic systems.	**Env Health** **Planning**	**Engineering** **Environment Protection Authorities**	**10k-100k**	**High**
PW2: Control and screen sediment laden runoff, waste, chemicals and fuels coming from disturbed/construction areas.	Minimise the extent of disturbed areas; rapidly revegetate disturbed areas; divert runoff around disturbed catchments; screen at the downslope of the disturbed areas to capture sediment and debris escaping from the development site.			**10k-100k**	**High**
PW3: Continue to refine, improve and implement Council's erosion and sediment control initiatives.	Promote education and awareness initiatives (e.g. marketing campaigns, fact sheets & training); enforcement activities (e.g. on the spot fines); improve development assessment and engage surface water management officers (i.e. DA compliance and sediment control officers)	**Planning**	**Community**	**100k-250k**	**Medium**
	Apply appropriate planning prior to the commencement of developments and review, monitor and maintain management practices and educate contractors on the correct installation and management of surface water quality controls/ devices.			**100k-250k**	**Medium**
	Maintain environmental management systems (e.g. ISO 14000) to ensure quality assurance in construction and maintenance works for protecting surface water quality.	**Env Health**	**Environment Protection Authorities**	**10k-100k**	**High**
PW4: Identify, control and treat point and diffuse source pollution impacts from industrial areas.	Undertake environmental audits of industrial and commercial premises to assess the effectiveness of pollution management practices and to identify activities that pose a high risk to surface water quality.			**10k-100k**	**High**
	Develop and implement an environmental incidence response program to capture, control and reduce hazardous spills.			**10k-100k**	**Medium**
	Undertake street sweeping and evaluate the potential to modify existing Council practices to maximise the capture of pollutants economically and environmentally.			**250k-2M**	**Low**

3.3.3 Protect and Enhance Urban Surface Water Quality (cont'd)

Objective	Action	Responsibility	Support	Cost $	Priority
PW5: Establish a sewage impact management plan to remediate the effects of wastewater effluent and to use effluent as a renewable resource.	Assess the impacts of domestic onsite sewage systems and regional sewage treatment plants and prepare an options study to examine the use of effluent as a renewable resource.	**Env Health**	**CMA EPA Planning**	**10k-100k**	**High**
PW6: Initiate and apply a water cycle environmental levy to support catchment based water quality improvements that support the principals of asset management and ecologically sustainable development.	Undertake research studies to assess anthropogenic impacts and to develop stormwater enhancement technologies to remediate runoff from developed catchments.	**Water Cycle Steering Committee**	**Research Intuitions LGA Environmental Protection Authorities Env Health**	**100k-250k**	**High**
	Develop and apply catchment remediation programs to support surface water quality outcomes by the removal of sediments, nutrients and bacterial contamination (i.e. GPT's, wetlands, trash devices, street sweeping, spill response, education and industrial audits).	**Env Health Engineering**		**250k-2M**	**High**
	Implement ongoing management and maintenance of stormwater quality improvement devices.	**Engineering**		**100k-250k**	**High**
	Monitor, evaluate and report on the performance of surface water quality devices and the catchment based remediation program.			**10k-100k**	**High**
PW7: Review the water quality monitoring program to identify catchment pollution export relationships from different land uses.	Apply the findings of the water quality monitoring program to prioritise and remediate high pollution areas.	**Env Health**	**Engineering**	**100k-250k**	**High**
	Establish a regional water quality program to encourage the sharing of water quality data across catchments and to identify impacted areas and cost effectiveness of resources.			**100k-250k**	**High**
PW8: Research innovative and effective surface water treatment devices/ techiques and practices to treat surface water pollution effectively.	Research to assess best practices in site selection and designs best suited for the local government area for surface water treatment techniques.	**Env Health**	**Engineering**	**10k-100k**	**High**
	Include ecological protection, aesthetics, education, safety, and maintenance on all surface water treatment projects.			**100k-250k**	**Medium**
	Undertake monitoring of water quality treatment practices to evaluate individual effectiveness and to allow modelling to occur.			**10k-100k**	**High**
PW9: Promote the effectiveness and justification of the water cycle environmental levy.	Communicate the benefits of surface water treatment techniques and explain why treatment devices are being built.	**Community**	**Env Health Engineering**	**10k-100k**	**Medium**
PW10: Establish a Water Cycle Development Control Plan and guidelines for treating surface water pollution.	Research and prepare a water cycle DCP that details the values of the water cycle and techniques and effectiveness of capturing, treating and re-using surface water.	**Planning**		**10k-100k**	**Medium**

3.3.4 Protect Groundwater Environments

Objective	Action	Responsibility	Support	Cost $	Priority (Years)
PG1: Prepare and implement a groundwater management plan to ensure the protection and sustainability of groundwater resources.	Undertake a groundwater study in association with neighbouring local government areas to identify the availability of groundwater resources and assess environmental risk.	**Env Health** **Regional Groundwater Management Committee (RGMC)** **Community**	**Natural Resource Authorities** **Catchment Management Authorities** **Planning** **Engineering**	**100k-250k**	**1-3**
	Establish long term management options to assess groundwater sustainability and to prevent groundwater degradation.				
	Develop a program to monitor groundwater quality and quantity by collecting data from flow meters bores.			**250k-2M**	**1-3**
	Ascertain sustainable yield estimates of groundwater and investigate options to reduce shallow groundwater aquifer extractions.				
	Ensure the community and benefactors of groundwater resources are aware of the regulative requirements and the significance of maintaining groundwater and groundwater dependent ecosystems free of contamination.			**10k-100k**	**1-3**
	Ensure town water supply reliance from groundwater is afforded priority from potential risks and hazards.	**RGMC** **Community**	**Env Protection Authorities**	**10k-100k**	**1-3**
PG2: Assess the availability and impacts of groundwater resources.	Initiate groundwater mapping using GIS systems to assess the potential risk areas from proposed developments and the effects of cut and fill disturbance to aquifer storage and groundwater recovery.	**WCSC** **Env Health** **Engineering**	**Planning** **Research Institutions**	**100k-250k**	**3-6**

3.3.4 Protect Groundwater Environments (cont'd)

Objective	Action	Responsibility	Support	Cost $	Priority (Years)
PG3: Develop and implement a groundwater management plan to assess the vulnerability and risks to groundwater resources.	Establish a regional groundwater management committee with local and state governments, community and technical representatives to develop groundwater management plans that will set out the operating rules for sharing and protecting groundwater at a regional and local level.	**Regional Groundwater Management Committee (RGMC)** **Env Health**	**Planning** **Natural Resources Authorities** **Planning**	**100k-250k**	**1-3**
	Undertake studies to assess groundwater water quality and identify the most beneficial use of groundwater resources.			**100k-250k**	**1-3**
	Undertake monitoring to ensure that the use of groundwater resources is not compromised by addressing groundwater impacts from land use modifications.			**10k-100k**	**1-3**
	Monitor the level of activity in relation to contaminated sites, vulnerability maps, beneficial use maps and industry guidelines.			**10k-100k**	**3-6**
PG4: Incorporate planning instruments that influence the type of land use that is permissible for groundwater extraction.	Apply environmental planning processes that will identify groundwater issues that need to be address in development control plans, local environmental plans, regional environmental plans and state environmental planning policies.	**Planning**	**RGMC**	**10k-100k**	**3-6**
PG5: Integrate groundwater management plans with the water cycle balance assessment strategy and catchment planning to ensure consistency.	Review seasonally groundwater usage, groundwater quality, water level data and integrate with the findings of the water cycle balance assessment.	**Regional Groundwater Management Committee**	**WCSC**	**10k-100k**	**3-6**
PG6: Develop groundwater protection "best practice" guidelines suited to the local government area.	Collaborate with the regional groundwater management committee and with neighbouring local governments to develop day to day operating management guidelines for groundwater activities and decision making.	**Water Cycle Steering Committee** **Env Health**	**RGMC Planning**	**10k-100k**	**3-6**
	Develop management practices in regards to licensing bores, procedures for abandoning bores and water quality standards for extraction and using groundwater.			**10k-100k**	**1-3**
PG7: Develop an educational program promoting the importance and vulnerability of groundwater systems.	Use the local press, internet, educational kits and brochures to promote sustainable groundwater use and the risk associated with overextraction and contamination of groundwater resources.	**Community**	**RGMC**	**10k-100k**	**1-3**
	Develop a groundwater policy that will discourage groundwater use and encourage effluent re-use.	**Env Health**	**WCSC**	**100k-250k**	**1-3**

3.3.4 Protect Groundwater Environments (cont'd)

Objective	Action	Responsibility	Support	Cost $	Priority
PG8: Evaluate groundwater vulnerability from human impacts.	Assess and identify land uses that are impacting groundwater resources i.e. depletion of aquifers, deterioration of groundwater quality and land subsidence due to groundwater extraction for urban development.	**Planning** **Env Health** **Engineering**	**Regional Groundwater Management Committee** **Water Cycle Steering Committee** **Primary Industry Authorities**	**10k-100k**	**Medium**
PG9: Establish a groundwater vulnerability mapping assessment criteria to asses high risk areas.	Develop and implement groundwater vulnerability mapping to evaluate the impact of specific land uses and contamination sources.			**250k-2M**	**Medium**
	Implement a groundwater vulnerability mapping assessment based on the findings of the groundwater studies to determine water depth, recharge, soil properties, unsaturated and saturated zones and topography.			**10k-100k**	**Medium**
PG10: Introduce computer based tools to aid the process of groundwater mapping and risk assessment.	Integrate Geographical Information Systems (GIS) to present and analyse data on a spatial format from remote sensing, soil surveys, land surveys, water sampling sites, topographic maps and census data.			**250k-2M**	**Medium**
	Investigate and engage software systems to test and install computer generated mapping systems (i.e. DRASTIC) to identify homogeneous settings and subdivide areas into square grid raster maps to generate vulnerability groundwater maps.	**Engineering**	**Env Health** **Planning**	**250k-2M**	**Low**
PG11: Ensure that groundwater dependent ecosystems (GDE's) are managed for present and future generations.	Maintain a "sustainable yield" by limiting long term average extraction and managing timing, volume, rate and depth of groundwater extraction critical for ecological health processes to remain viable.	**Env Health** **Natural Resource Authorities**	**Planning** **Engineering** **Primary Industries Authorities** **Research Institutions**	**10k-100k**	**High**
	Protect groundwater dependent ecosystems (GDE's) by maintaining critical groundwater threshold levels during dry seasons and establish buffer zones surrounding sensitive GDE's local environment.			**10k-100k**	**High**
PG12: Identify knowledge gaps for managing groundwater dependent ecosystems and groundwater resource management.	Apply the precautionary principle to protect GDE's in situations where scientific knowledge is lacking or research gaps are acknowledged.	**Regional Groundwater Management Committee**		**10k-100k**	**Medium**
	Develop and apply adaptive management processes and research to improve the understanding of GDE's and groundwater resources.				

3.3.4 Protect Groundwater Environments (cont'd)

Objective	Action	Responsibility	Support	Cost $	Priority (Years)
PG13: Apply water sensitive urban design planning to minimise adverse impacts by development on GDE's.	Maintain natural groundwater flow patterns that are critical for the water cycle, ecosystem health and groundwater sustainability.	**Env Health** **Planning** **Engineering**	**Water Cycle Steering Committee** **Env Protection Authorities** **Primary Industry Authorities**	**10k-100k**	**1-3**
	Prevent contamination of groundwater by preparing risk assessments identifying potential risk zones and ensuring rehabilitation processes are effective and practical.			**250k-2M**	**1-3**
	Adopt an integrated management approach by considering groundwater quantity and quality in relation to surface water, soils, vegetation and land use planning issues when making determinations concerning GDE's and groundwater.			**10k-100k**	**3-6**
PG14: Establish a regional base line data for groundwater dependent ecosystems.	Identify and define base flows, aquifers, wetlands and groundwater to assess the vulnerability and the significance of GDE's in the local region.	**Env Health**	**Research Institutions**	**100k-250k**	**3-6**
PG15: Integrate groundwater management plans with the water cycle management strategy and planning processes.	Ensure water cycle and groundwater management processes are integrated and consistent with clear linkages to relevant planning, environmental and social goals and objectives.	**Planning**	**Env Health**	**10k-100k**	**3-6**
PG16: Integrate and promote the significance of groundwater dependent ecosystems within Council.	Ensure land use planning instruments (i.e. Local Environmental Plans, Development Control Plans and State and Regional Planning Policies) identify GDE's significance.			**10k-100k**	**3-6**
PG17: Ensure "State of Environment" reporting includes groundwater resources.	Review and update groundwater management plans every five years and report on the effectiveness of the actions to sustain the health of groundwater systems.	**Regional Groundwater Management Committee**	**Water Cycle Steering Committee**	**10k-100k**	**1-3**
PG18: Promote and educate the community and stakeholders on the significance of groundwater resources.	Establish an ongoing educational program (i.e. press releases, State of Environment reports, internet, fact sheets etc.) that informs the community and participating stakeholders of the ecological, economic and aesthetic values of groundwater resources.	**Community**		**10k-100k**	**1-3**

3.3.5 Maintain Natural Stream Flows

Objective	Action	Responsibility	Support	Cost $	Priority (Years)
SF1: Establish a stream flow management plan that identifies stream flow sources and provides actions to maintain and enhance natural stream flows.	Undertake a stream rehabilitation assessment to identify barriers (i.e. sedimentation, weirs, drains, river crossings and obstructions that restrict fish migration and a reduction in stream flows.	**Env Health**	**Natural Resource Authorities**	**250k-2M**	**3-6**
	Undertake hydrological flow modelling to understand flooding effects to downstream environments before stream flows are modified.	**Engineering** **Env Health**	**Catchment Management Authorities** **Primary Industries**	**100k-250k**	**3-6**
	Undertake hydrological flow modelling to determine pre European benchmarks for natural stream flows.			**10k-100k**	**3-6**
	Modify existing flow paths to enhance stream flow without comprising flooding effects to downstream environments.			**100k-250k**	**3-6**
	Ensure stream flow management is an integral part of land use planning instruments (i.e. Local Environmental Plans, Development Control Plans and Regional and State Planning Policies) that recognises the importance and significance of natural stream flows.	**Planning**	**Planning Env Health**	**10k-100k**	**3-6**
	Lobby governments across all political boundaries for natural stream flows to be recognised formally under law as a legitimate use of water for the sustainability of the water cycle and ecosystem health.		**Planning Authorities**	**10k-100k**	**1-3**
SF2: Promote the ecological significance of stream flows, watercourses and open channels.	Establish a non piping policy that recognises watercourses and stream flows should be preserved and integrated within planning as an integral part of ecologically sustainable development.	**Planning**	**Engineering**	**10k-100k**	**1-3**
	Prohibit or minimised conventional straight line channels and maintain the natural characteristics of watercourses by adopting soft ecological practices (i.e. meandering, settling pools, riffle zones and riparian buffer zones).	**Env Health**	**Natural Resource Authorities**	**100k-250k**	**1-3**
	Water flowing to the sea should not be seen as wasted water as it nourishes the water cycle, (i.e. groundwater, streams, rivers wetlands and estuaries).			**10k-100k**	**1-3**
SF3: Increase community interaction and access to watercourses and waterway corridors.	Develop programs that promote the recreational, aesthetic and ecological significance of stream flows and provide greater public access to waterways, creeks and drainage corridors.	**Community Planning**		**10k-100k**	**6-10**
	Educate stakeholders affected by stream flow the effects of stream flow depletion.		**Env Health**	**10k-100k**	**1-3**

3.3.5 Maintain Natural Stream Flows (cont'd)

Objective	Action	Responsibility	Support	Cost $	Priority (Years)
SF4: Understand the effects of water retention on stream flow sustainability.	Apply modelling/research to determine the impacts of large scale water storage on stream flows and on ecosystem health.	**Water Cycle Steering Committee**	**Research Institutions**	**10k-100k**	**1-3**
	Assess the impacts from inter-catchment transfers and urban water demands.			**10k-100k**	**1-3**
	Revise planning, design and construction practices to achieve stream flow sustainability.			**10k-100k**	**1-3**
SF5: Understand the effects of urban planning on natural stream flows patterns.	Develop and implement strategic actions to reduce and combat floods and their negative effects while enhancing stream flow patterns that are important to the sustainability of ecosystem health.	**Engineering**	**Planning** **Env Health**	**100k-250k**	**3-6**
	Develop modelling and practical methodologies that can be used to understand stream flow patterns from the effects of land use activities (i.e. urban, commercial, rural, agriculture, forestry and industrial).			**100k-250k**	**3-6**
	Evaluate and provide a water balance allocation for irrigation, community water demand and for environmental needs.			**100k-250k**	**1-3**
SF6: Apply the precautionary principle on stream flows in uncertain situations.	Research best available knowledge and apply base stream flow standards to quantify variable flows that support ecological functions and social benefits.	**Water Cycle Steering Committee**	**Env Health** **Research Institutions**	**10k-100k**	**3-6**
	Understand and promote that ecosystems are continually evolving and are depended upon naturally variable flows to sustain their existence.			**10k-100k**	**3-6**

3.3.6 Climate Change

Objective	Action	Responsibility	Support	Cost $	Priority (Years)
CC1: Develop an understanding of the implications of climate change on the water cycle and to what options are available to local government.	Assess and understand the drivers of climate change and identify what it means and how local government can influence climate change at a local government level.	**Env Health Community**	**Research Institutions** **Env & Climate Change Authorities** **Local Government Association**	**10k-100k**	**3-6**
	Undertake hydrological modelling and desktop assessment to investigate potential climate change impacts on the water cycle in the local government area.	**Env Health** **Planning**		**100k-250k**	**3-6**
	Initiate studies to evaluate the effects of climate change and examined changing land use zones from areas which are more receptive to wet or dry soil moisture.			**10k-100k**	**3-6**
	Develop management plans endorsed by recognised international associations in national and international climate change forums to understand current best practices for managing climate change trends within the water cycle.	**Env Health**	**Planning** **Env & Climate Change Authorities** **Federal Climate Change Policy**	**10k-100k**	**1-3**
CC2: Develop community awareness on climate change and greenhouse associated issues in relation to the water cycle.	Educate, inform and encourage behavioural change within the community through public information campaigns, fact sheets and internet and school scholarships.	**Community**		**10k-100k**	**3-6**
	Promote research by supporting university scholarships to undertake research projects to evaluate corporate actions, evaluate household activities and industrial practices that effect climate change trends.			**100k-250k**	**3-6**
	Undertake behavioural surveys to gauge trends and community awareness on climate change.			**10k-100k**	**3-6**
CC3: Integrate water cycle climate change strategies with urban strategic planning.	Develop a water cycle climate change check list (i.e. water supply, conservation, energy, transport etc.) to highlight and mitigate the effects of climate change on the water cycle from urban planning.	**Water Cycle Steering Committee**	**Planning Env Health**	**10k-100k**	**1-3**
CC4: Develop and implement urban design planning to minimise the effects of climate change on the water cycle.	Design urban planning that reduces the reliance on car transport and promotes bicycle lanes, walking paths, public transport and encourages pedestrian friendly urban design layout.	**Planning**	**Env Health Engineering**	**250k-2M**	**6-10**

3.4 Conservation of water resources

3.4.1 Water Consumption Assessment

Objective	Action	Responsibility	Support	Cost $	Priority (Years)
WC1: Develop and implement a Water Demand Management Plan to assess the demand for water resources and understand how and where water is used.	Undertake an assessment on the water demands from the perspective as a water service supplier, participating customer and community demand.	**Env Health** **Engineering**	**Water Cycle Steering Committee** **Community** **ICLEI Water** **Catchment and State Authorities** **Water Utilities**	**100k-250k**	**3-6**
WC2: Develop partnerships with agriculture, manufacturing, residential and water distribution sectors to understand and minimise water consumption.	Quantify and identify who and what are the main industries water users within the local government area.			**10K-100k**	**1-3**
	Evaluate the water consumption balance by modelling consumption inputs and outputs such as inter-catchment transfers, STP flows, water conservation practices and groundwater extraction.			**10k-100k**	**3-6**
WC 3: Evaluate the costs and benefits of water demand and conservation practices.	Assess the cost effectiveness and benefits of water conservation management taking into consideration, administration, capital works, plant and water efficient appliances and community education.			**10k-100k**	**3-6**
	Understand the economics of water demand management prior to implementing water conservation programs.			**10k-100k**	**3-6**
WC4: Develop and apply water savings plans and audit water demand to examine the effectiveness of water conservation practices.	Undertake water efficiency audits on all Council assets to evaluate consumption and identify and rectify water losses.			**10k-100k**	**1-3**
	Apply End – Use modelling to investigate options in water efficiency and water demand by the community and Council.			**10k-100k**	**3-6**
	Collect Council historical water consumption data for the local region and apply end-use modelling to forecast consumption and implement options for reducing water consumption.			**10k-100k**	**3-6**

3.4.1 Water Consumption Assessment (cont'd)

Objective	Action	Responsibility	Support	Cost $	Priority (Years)
WC5: Promote water conservation practices to industries and community sectors that are high water users and reward water efficiency excellence within industry and the community.	Identify and target industry high consumption users (i.e. agriculture) and promote cost effective and environmentally responsible alternatives such as water recycling, re-use and sewer mining.	**Env Health**	**Water Utilities** **Catchment and State Authorities**	**10k-100k**	**1-3**

3.4.2 Water Conservation Management Programs

Objective	Action	Responsibility	Support	Cost $	Priority (Years)
MP1: Develop Water Conservation "Guidelines" incorporating demand, conservation and savings practices to improve water conservation within Council and the local government area.	Develop a water conservation policy with clear realistic targets to gauge the performance of management plans and to reduce water consumption.	**Env Health**	**Catchment and State Authorities. Water Utilities**	**10k-100k**	**3-6**
	Apply water reuse and water efficiency programs practices on Council facilities.	**Engineering Community**		**10k-100k**	**3-6**
MP2: Develop and introduce a Water Conservation and Reuse Development Control Plan to regulate and impose water conservation conditions on development applications.	Endorse and condition water conservation policy targets and practices in all development control plans and condition development applications.	**Planning**	**Env Health Catchment Authorities State Authorities**	**100k-250k**	**3-6**
MP3: Promote the benefits of water efficient fixtures within the community.	Promote water efficient urban water use within urban/household communities by encouraging the fitting of water efficient fixtures in households during the development approval process.			**10k-100k**	**1-3**
	Promote the benefits of water conservation fixtures without the need to change behavioural habits, i.e. lowering energy bills.			**10k-100k**	
MP4: Assess, rate and retrofit water conservation programs/practices to Council facilities and the community to improve water conservation efficiency.	Modify Council facilities with water efficient fixtures and mandate water efficient fixtures for new developments.	**Engineering**		**100k-250k**	**6-10**
	Undertake water efficiency audits within the industry in collaboration with Environmental Audit reviews.	**Env Health**		**10k-100k**	**1-3**
MP5: Develop rainwater tank guidelines evaluating best practices, planning, public health, social, cost effectiveness and the cumulative environmental impact on the water cycle.	Model the environmental impacts from the effects of rainwater tanks on the water cycle if the majority of dwellings were to be fitted with rainwater tanks.	**Engineering Env Health**	**ICLEI State Authorities Water Utilities**	**10k-100k**	**3-6**
MP6: Understand the broad implications of water conservation measures on the water cycle.	Undertake a literature review on the effects of water retention and conservation measures on the water cycle.	**Env Health**	**Water Cycle Steering Committee Research Institutes**	**10k-100k**	**3-6**
	Collate water quality data and develop modelling scenarios relating to the long term impacts on the water cycle from water conservation practices.			**10k-100k**	**1-3**

3.4.2 Water Conservation Management Programs (cont'd)

Objective	Action	Responsibility	Support	Cost $	Priority (Years)
MP7: Identify and assess water conservation and reuse opportunities within Council facilities and industry.	Undertake feasibility studies on recycling, sewer mining, and stormwater harvesting projects involving sewage treatment plants, golf courses, bowling clubs, aquatic centres, nurseries and sporting and recreational park lands.	**Engineering**	**Water Cycle Steering Committee Planning Research Institutions**	**250k-2M**	**1-3**
	Assess water conservation viability by modelling Council facilities and industries to identify water recycling and sewer mining opportunities.			**10k-100k**	**1-3**
MP8: Source government funding to undertake water conservation and reuse programs.	Pursue external grant sources (i.e. Government) to undertake water reuse, sewer mining and stormwater harvesting projects.	**Community** **Env Health**	**Water Cycle Steering Committee** **Catchment and State Authorities**	**10k-100k**	**3-6**
	Collaborate and develop partnership consortiums with research institutions, water utilities and community to support funding proposals.			**10k-100k**	**6-10**
MP9: Work in partnership with sewage treatment plant and wastewater utilities to design and implement a water reuse strategy and action plan for tertiary treated wastewater.	Prepare a feasibility and options study and risk assessment study to reuse treated wastewater.			**10k-100k**	**6-10**
	Identify and quantify costs and benefits of reusing effluent from sewage treatment plants and waste water sources.	**Water Cycle Steering Committee Community Water utilities**	**Catchment and State Authorities**	**10k-100k**	**3-6**
	Minimise ecological impacts to waterways by reducing nutrient rich tertiary treated freshwater entering the estuary/waterway or ocean.			**10k-100k**	**1-3**

3.4.3 Community Education, Attitudes and Barriers

Objective	Action	Responsibility	Support	Cost $	Priority (Years)
CE1: Establish a community forum to promote community information exchange and education regarding water conservation and reuse of water resources.	Communicate and promote the benefits of water conservation programs to the community, schools and industries.	**Community** **Env Health** **Planning** **Engineering**	**Water Cycle Steering Committee** **Natural Resource and Planning Authorities** **Water Utilities**	**10k-100k**	**3-6**
	Promote water conservation milestones and achievements in reducing water demand and savings through social fun days, fact sheets, State of Environment Report, community groups, clubs, industries and Council's Web page.			**10k-100k**	**1-3**
	Facilitate discussion and debate regarding water conservation and changing community attitudes in relation to water use and conservation outcomes.			**10k-100k**	**3-6**
CE2: Encourage the community to support and embrace water conservation initiatives.	Introduce community financial incentives to promote and encourage water conservation initiatives.	**Community** **Water Cycle Steering Committee**	**National and state natural resource Authorities** **Water Utilities** **Catchment and Planning Authorities**	**250k-2M**	**3-6**
	Identify and reward good industrial role model industries that use innovative and effective water conservation practices.			**10k-100k**	**1-3**
	Engage the community early, on recycling/reuse proposals to promote trust and ownership within the community.				
CE3: Promote water conservation lifestyle living and encourage best practice water use efficiency throughout the community.	Interact with the Community to discuss and clarify uncertainty regarding negative perceptions of water reuse and sewer mining.			**10k-100k**	**3-6**
	Promote and encourage community catchment, garden and irrigation water use efficiency awards.			**10k-100k**	**1-3**
CE4: Lobby Governments, authorities, politicians and high profile advisory committees to advance water conservation and reuse programs.	Influence Federal and State Government's attitude/position in regards to water reuse standards to enable water reuse for public pools and sportsgrounds.	**Water Cycle Steering Committee**	**Env Health** **Planning**	**10k-100k**	**1-3**
	Develop national guidelines for water reuse that provide a nationally consistent approach to treatment, reuse and recycling of sewage effluent in response to State inconsistencies and lack of uniformity in recycling approaches (see Appendix A).			**100k-250k**	**3-6**
	Gain political, scientific and regulatory support to advance the success of water reuse schemes (NWQMS *Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2) - Augmentation of Drinking Water Supplies* 2007).				

3.4.3 Community Education, Attitudes and Barriers (cont'd)

Objective	Action	Responsibility	Support	Cost $	Priority Years
CE5: Work in partnership with the community to eliminate barriers and to achieve water conservation goals.	Review legislative requirements and identify regulative barriers that may inhibit the advancement of water conservation.	**Planning**	**Env Health**	**10k-100k**	**6-10**
CE6: Promote Council's water conservation public image by leading through example.	Ensure Council facilities and buildings represent good role models in water conservation**.**	**Community Engineering**	**State and Catchment Authorities**	**100k-250k**	**3-6**
	Demonstrate commitment to water conservation by adopting "best practices" throughout the public sector.	**Community** **Env Health**	**National and State Natural resource Authorities** **Catchment Authorities** **Water Cycle Steering Committee**	**250k-2M**	**3-6**
	Promote financial savings achieved by implementing water efficiency plans in contrast to costly water audits.			**10k-100k**	**3-6**
	Ensure water efficiency targets are met in new Council owned or leased buildings.			**10k-100k**	**6-10**
CE7: Enhance and strengthen water conservation education programs.	Undertake a water conservation benchmark survey involving, knowledge, attitudes, skills and behaviour of the local government area.	**Community**	**Water Cycle Steering Committee** **Env Health** **Planning**	**10k-100k**	**3-6**
	Review and repeat survey every five years to monitor the communities response to water conservation issues.			**10k-100k**	**6-10**
	Use survey results to identify barriers and opportunities to improve water conservation behaviour and design educational strategies.			**10k-100k**	**6-10**
	Monitor and evaluate the effectiveness of the water conservation programs.			**10k-100k**	**3-6**
CE8: Develop and apply Key Performance Indicators (KPI's) to assess the effectiveness of water conservation and reuse strategic actions.	Audit greywater, stormwater, sewer mining and recycled projects within the community.	**Env Health**	**Community**	**10k-100k**	**3-6**
	Audit new development applications that include water conservation practices.			**10k-100k**	
	Determine whether freshwater outputs are increasing from sewage treatment plants.			**10k-100k**	

3.6 Discussion

The Hydrological Cycle is one of the essential processes for sustaining life on the Earth, of the 2.5 percent freshwater available only 0.5 percent is available for human consumption.

Demands on our natural environments and water resources have been increasing globally with population growth and as a consequence environmental managers need to manage water resources more effectively and sustainably. Emerging trends have shown that much of the environmental impacts on our water resources are the result of mismanagement. In response to these concerns this project, has developed a generic water cycle management strategy for local government to manage water resources effectively and holistically as part of the water cycle.

Water cycle management strategies are valuable tools for initiating actions in response to urban pressure. Strategies should be supported and integrated with scientific knowledge and efficient management strategies that incorporate prediction and acknowledgment of uncertainty to accommodate emerging environmental issues.

In general, water cycle management strategies were driven by political pressures influenced by economic factors and environmental conditions involving prolong drought and climate change. Consequently, many water cycle strategies reflected political bias towards water demand/re-use management and water conservation strategies with very minimal understanding of the total water cycle.

In regional areas of Australia, water cycle management strategies focused mainly on optimising water supply benefits and sewerage services. The ecological benefits derived from this approach are and have been limited and should be expanded to encompass the broader ecological landscape within the total water cycle.

In the metropolitan areas of Australia, water cycle management strategies focused on water demand and supply linking water conservation, wastewater treatment and stormwater management initiatives. Strategies further recognised population growth, drought, climate change, pollution prevention and river health as having a major influence on water resources. It's unclear however, as to what strategic capacity water cycle management has been applied within the overall water management infrastructure.

Exploitation of groundwater resources was highlighted in most strategies as an alternative water source which raises concerns to the sustainability of groundwater resources. Most strategies were broad and reactive to water issues and showed minimal understanding of the long term consequences of the water cycle and its interaction within the environment. A common shortfall amongst the strategies was the omission of key performance indicators to gauge the effectiveness of the strategies. Climate change was used consistently to excuse Government’s incompetence for managing water resources more effectively.

International approaches to water cycle management strategies have been resource intensive and overly technical to be used by local governments. The research had shown minimal understanding of the interrelationships of the water cycle and the urban environment or what strategic approach required to be taken to manage the water cycle holistically at a local level.

In Europe water strategies have focused on setting objectives to ensure all waters achieve “good status” by initiating steps to prevent deterioration to aquatic environments. The rationale concentrated on water pricing and promoting more sustainable uses of water resources. The general feeling is that competing needs from countries within the European Union may not provide fair and sustainable use of water resources between neighbouring countries. It is also unclear how water ownership and water rights will be regulated in a sustainable way throughout the European Union.

In South Africa water cycle management placed a higher emphasis on developing a scientific understanding of the hydrological cycle in contrast to water demand and water reuse. The South African approach highlighted that supporting research and developing technologies would provide a scientific explanation that would result in good long term and sustainable management practice. Alternatively, the South African approach may be viewed as too technical, far reaching, resource intensive and financially demanding for local government applications.

Water cycle management in the United States tended to be very parochial with a high emphasis on ‘global’ change and scientific assessment. Programs in water cycle management were resource intensive and highly science orientated with links to NASA satellite sensor remote imagery technologies to assess global water cycle variability.

Programs included the determination of how natural fluctuations and anthropogenic elements impact the water cycle and how the water cycle functions as a transport agent for mass and energy.

A case study reviewed Hornsby Shire Council's Sustainable Total Water Cycle Management Strategy. The Strategy involved a strategic action plan and catchment modelling to aid planning and land use impact projections. This Strategy focused on maintaining natural flows, enhancing water quality, re-use and fostering partnerships with the community. The Strategy incorporated holistically existing programs such as estuary management, catchment remediation and water quality monitoring for managing water resources of the local government area.

The Strategy had minimal performance indicators to evaluate its effectiveness for achieving sustainable outcomes. Groundwater, stream flows, infiltration and evaportranspiration rates or the assessment of the water cycle were not considered within the Strategy.

The capacity for catchment modelling to predict environmental change is questionable due to inherent complexities in relation to data processing and output variability. Hydrological and ecological modelling invariably is suited to catchment scale predictions which can dilute point source impacts and are highly variable in respect to outcomes. More importantly, there seems to be a deficiency within industry to integrate catchment modelling and geographical information systems.

The Hornsby Shire Council approach to environmental/water cycle management has provided a catalyst for developing concepts in water cycle management within this research. Programs such as sustainable water cycle management, estuary management and catchment remediation are widely recognised. Water quality monitoring programs are highly respected with data sets extending over 12 years. This commitment to water quality monitoring has been crucial to instilling confidence in estuary process studies, water quality and modelling outcomes.

Local governments due to their limited resources are restricted by their temporal and spatial scale monitoring. As a result, ecological process studies, water quality and environmental assessments can be incomplete due to their "snap shot" assessment of the study area. There is also a heavy reliance on existing literature to minimise the cost of commissioning field studies which may not be applicable to the study area.

The integration of environmental research and management has been crucial in achieving ecological sustainability. The ability to transpose research outcomes into practical planning and regulative instruments is essential.

There is a need for water cycle management strategies to be multidisciplinary that provides local government decision makers with appropriate tools to achieve ecologically sustainable development. This implies maintaining an optimum balance between protecting the environment, the efficient utilisation of water resources and applying adaptive management to review and responding to environmental change. In response to this need a generic water cycle management strategy template for managing the water cycle has been developed for local government.

The Generic Water Cycle Management Strategy developed by this project is based on three main themes. The first theme involves **the assessment of the water cycle** which forms part of a risk assessment where threats and condition assessment determine the health of the water cycle. Significant areas that have been recognised within the strategic element include the water balance, water quality, stream flows, ecological health and modelling. This strategy forms the basis for planning, implementing and evaluating management activities and provides information that supports informed decision making for the management of the water cycle.

Data collected by the assessment of the water cycle provide specific information on the existing condition of the various elements of the water cycle that can be used to prioritise areas for existing and future management activities and can further provide understanding about water cycle processes and environmental condition over space and time, and the evaluation of performance indicators.

The second theme includes **the management of human induced impacts on the water cycle.** The process of defining human induced impacts on the water cycle is complex and encompasses all of the human induced interactions activities. The theme focuses on existing and emerging anthropogenic impacts on a local government scale and develops a management framework of actions for minimising human-induced impacts from surface to groundwater in relation to planning, governance, urban design, water quality, groundwater, stream flows and climate change.

The third theme focuses on the application of **water conservation methods of water resources.** Population growth and economic development globally are increasing the demand in water resources which has more than tripled over the last 50 years. Consequently, the supply of water will become a major issue for future expanding urban settlements. The prediction is that the population in Australia will generally increase dramatically from 20 million to 27 million by 2050. In this regard local governments are obligated to seek alternatives in water conservation and re-use initiatives which have enormous potential for replacing potable water. This also means that less water will be extracted from natural resources affecting the water cycle. Approximately 37 percent of reticulated water in Australia is used for garden watering where recycled or stormwater harvesting could be utilised.

In general, water reuse schemes in Australia have been poor in comparison to other countries. The conservation, recycling and reuse of water is now recognised as a key component in water resource management. Water conservation strategies developed actions in regards to water conservation / reuse, consumption, community education, attitudes, and barriers and proposes management programs to use water more efficiently.

The performance of the Generic Water Cycle Management Strategy can be measured against realistic environmental standards (i.e. predictive modelling, water quality, water cycle balance, stream flows, management targets and community expectations (e.g. surveys) to gauge the effectiveness of the strategy.

To enhance the effectiveness of the Strategy it is important to ensure communication between stakeholders is effective and clear. To achieve this objective pooling of information for a common goal will provide confidence within the science and management sectors. Managers should acknowledge the benefits of using best practice based on credible science, recognising that scientific knowledge may be incomplete. In contrast the science sector needs to take a more holistic approach in view of its interaction with social and economic values and ensure technical information is express clearly to managers. As a result this project has developed an effective generic water cycle management strategic decision framework tool to better manage the water cycle for local government.

4.0 Conclusion

This project has successfully achieved its aim by producing a Generic Water Cycle Management Strategy as shown in Table 9. The Strategy has merged scientific and managerial ideologies with innovative concepts into one holistic approach for managing the water cycle for local government.

The project has further accomplished it's objectives by defining the water cycle and its interactions with the environment and has reviewed management practices/concepts. A case study was undertaken to examine water cycle management by a local government in response to development pressure.

The findings showed that water cycle management strategies were driven by environmental and political pressures such as droughts and climate change. As a result many water cycle strategies reflected political bias towards water demand/reuse management and water conservation programs with minimal understanding and appreciation of the total water cycle.

Internationally, water cycle management strategies were resource intensive, far reaching and highly technical to be applied by local governments. Few strategies were holistically integrated or understood the interrelationships of the water cycle and the natural and urban environment.

Based on the findings, a new approach in water cycle management has been formulated. This approach is based on a premise that to manage the water cycle, authorities and environmental managers must first define the processes and understand how the water cycle interacts within the natural and urban environment. As a result a strategic framework was developed consisting of three themes.

The first theme focused on assessing the condition of the water cycle by developing strategic actions to determine the water balance, water quality, stream flows, ecological health and modelling of the water cycle. The theme further developed operational actions to understand how water moves through the environment from air to ground, and how it is intercepted, stored below the surface, recharged and release through streams and oceans.

The second theme involved the management of human induced impacts on the water cycle. This theme included strategic actions that incorporated planning, governance water sensitive urban design, the protection and enhancement of surface water quality. This theme included operational strategic actions for the protection of groundwater environments and the preservation of natural stream flows and climate change strategies consistent to ecological sustainable development.

The third theme focused on applying water conservation strategic programs. The theme detailed actions to address water consumption, attitudes and barriers in relation to water conservation and reuse and management programs for water conservation practices.

The Generic Water Cycle Management Strategy for local government is presented in Table 9. The strategy is a valuable management tool for local government to address issues pertaining to the management of the total water cycle. It provides an effective water cycle management strategic decision framework to enhance decision makers for the assessment, management and conservation of water resources. It further provides an excellent foundation for local government to adopt "best practice strategies" that integrates science, management and the community for managing the water cycle in an ecological sustainable manner. Undoubtedly, the Strategy will be influenced by external factors such as behavioural changes, technical knowledge and political pressure from the electoral cycle agenda. Other limiting effects may be operational costs in regards to budgetary constraints and biases towards development and associated externalities that may prevent in applying the precautionary principle in situations of uncertainty.

The Strategy, subject to the local constraints can be applied in stages or in its entirety to small or large scale applications to achieve sustainable water cycle outcomes as a tool to manage the water cycle.

4.1 Recommendations

The following recommendations are presented to local governments for consideration in regards to water cycle and environmental strategies.

- Greater emphasis needs to be applied by local governments on integrating science and management methodologies for managing the water cycle environment.
- Local governments should consider the water cycle as a holistic system incorporating uncertainty, adaptability and flexibility to accommodate changing trends.
- Local governments and community stakeholders must have common goals in understanding the anthropogenic effects of the water cycle.
- Integrated water cycle management strategies should be expanded to encompass the broader ecological landscape within the total water cycle.
- Local governments need to have a balanced triple bottom line appreciation of environmental, economic and social values in regards to water cycle management strategies.
- A minimum eight to ten year water quality data should be undertaken by local governments to instil confidence in environmental monitoring/assessment programs and catchment modelling.
- Local government consortia comprising of neighbouring local government areas should be establish to share resources and consolidate priorities in water cycle issues.
- Local government boundaries should be consistent with catchments boundaries to enhance a holistic and efficient approach to water cycle management.
- Local government environmental management committees should integrate scientific and technical specialist, research intuitions, agencies state and community stakeholders, in house specialist and local government representatives.
- Local governments should ensure research outcomes are acknowledged and incorporated into practical planning and regulative instruments to justify further research work.
- Local governments should encourage innovation in water conservation and re-use within the organisation and the community in water efficiency audits, water efficient fixtures, wastewater re-use and efficient irrigation practices.

- Local governments should incorporate an adaptive management methodology that increases the understanding of multiple processes through active participation and learning, evolving experimentation and reviewing and responding to change in regards to water cycle management.
- Local government water cycle management strategies should ensure that the assessment of the water cycle, the management of human induced impacts and the application of water conservation methods are included within the strategic framework.
- Local governments should gauge the performance of water cycle strategies against realistic environmental standards, management targets and community expectations and values.
- Local governments should ensure and promote clear information links that allows better communication between scientist and managers of natural resources.
- Local governments should acknowledge the benefits of using best practice based on credible science and conversely it should also be acknowledged that scientific knowledge may be incomplete.
- Local governments should adopt the ‘precautionary principle’ in decision making to instil caution and duty of care in regards to development pressure on the water cycle environment.

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6.0 Appendices

Appendix A: NSW, Queensland and Victoria - Water Quality Guidelines for the use of Reclaimed Water

Terms and Interpretations

The following distinctions are made in regards to the ‘reclaimed water’ guidelines;

Term	Definition
Direct Potable	This process involves the treatment of wastewater to such an extent that it can be fed into a potable treatment or supply system. At present there is no legal requirement for reclaimed water to be substituted for fresh water- there is no federal, state or local government endorsement or requirement for the use of treated reclaimed water for potable purposes. NSW, Victoria and Queensland have not endorsed direct potable use from reclaimed water (*Guidelines for Environmental Management - Use of Reclaimed Water* 2003; *Queensland Guidelines for the Safe Use of Recycled Water* 2004), “Primarily, this Guideline for Environmental Management applies to the use of reclaimed water from sewage treatment plants”(*Guidelines for Sewerage Systems - Use of Reclaimed Water* 2000)
Disinfection System	Disinfection systems refer to chlorination, ultraviolet irradiation or other disinfection systems. Monitoring requirements include checking chlorine residual. Monitoring frequencies do not apply to pond or lagoon systems.
Helminths controls	Helminths controls include measures such as removal by treatment, veterinary inspection, cattle husbandry and/or a withholding period prior to grazing.
Indirect Potable	This involves the augmentation of groundwater and surface waters with reclaimed water. Water may then be extracted from these sources and subsequently treated for potable purposes.
Nitrogen & Phosphorus	No requirement is provided – site specific.
Pathogen Reduction	Pathogen reduction beyond secondary treatment may be accomplished by disinfection e.g. chlorine, or by detention ponds or lagoons. Systems using detention only do not provide reduction of thermotolerant coliforms counts to <10 per 100mL and are unsuitable as the sole means of pathogen reduction for high contact uses.
pH	90% compliance for samples.
Primary Treatment	Initial treatment - removing (by screening) sedimentation and solids.
Urban (Non – Potable) Municipal	Similar as residential applicable to public and community reserves with a higher degree of safeguards and controls to minimised and restrict public access.
Urban (Non-Potable) Residential	Reclaimed water suitable for application under a range of urban uses such as irrigation of open spaces, cleaning, dust suppression etc, as the level of contact increases so does the quality of the reclaimed wastewater.
Reclaimed Water	Reclaimed water refers to the quality of water following treatment appropriate for a particular application and prior to mixing with the receiving waters or water derived from wastewater and treated to a level appropriate for its intended application.
Secondary Treatment	Generally, a level of treatment that removes 85% of BOD and SS, by biological or chemical treatment processes. Second effluent generally has BOD <30mg/L, SS<30mg/L but may rise to >100 due to algal solids in lagoon to ponds systems .
Tertiary Treatment	Treatment processes that exceed secondary and biological processes which further improve effluent quality. Tertiary processes include detention ponds, sand filtration, dual media or membrane filtration and wetland polishing(*Guidelines for Sewerage Systems - Use of Reclaimed Water* 2000).
Turbidity	Limit met prior to disinfection. 24 hour mean value. 5 NTU maximum value not to be exceeded.

Reclaimed Water for Indirect Potable Use

Reference Source	Type of Re-Use	Level of Treatment	Quality	Monitoring	Comments
(***Queensland Guidelines for the Safe Use of Recycled Water* 2004)**	**Surface Water – Direct injection to aquifer**	Secondary & Pathogen reduction	<1000 cfu /100ml	pH weekly Disinfection systems daily	Quality should comply with raw drinking water guidelines at abstraction point.
(*Guidelines for Sewerage Systems - Use of Reclaimed Water* 2000)	**Surface Water / STP - Direct injection to aquifer**	Tertiary – Advanced	<10cfu/100ml Turbidity <2 NTU 1mg/L Cl residual pH 6 - 8.5	Weekly Disinfection continuous. Site specific depending on the receiving water quality	High human contact and medium risk of ingestion. Project specific assessment should take place that includes contaminant monitoring health and safety testing.
(*Queensland Guidelines for the Safe Use of Recycled Water* 2004)	**Groundwater** (Recharge by ***spreading*** into potable aquifer)	Secondary - Tertiary (Nutrient reduction site specific) & pathogen reduction	Site specific, must have no deleterious effects on aquifer water quality or land resource. <1000 cfu/100ml	pH weekly	Quality should comply with raw drinking water guidelines.
(*Guidelines for Sewerage Systems - Use of Reclaimed Water* 2000)	**Groundwater – percolation into aquifer.**	Tertiary & Pathogen reduction	<1000 cfu /100ml SS mg/L 1mg/LChlorine residual pH 6-8 .5	Monthly Disinfection continuous	Minimum 3m depth to aquifer. Groundwater should comply with Australian Drinking Water Guidelines for raw water after mixing.
(*Guidelines for Sewerage Systems - Use of Reclaimed Water* 2000)	**Groundwater** (Recharge by ***injection*** into potable aquifer**)**	Secondary - Tertiary (Nutrient reduction site specific) & pathogen reduction	Site specific, must have no deleterious effects on aquifer water quality or land resource. <10cfu/100ml	pH weekly coliforms weekly Disinfection systems daily	Clogging prohibited. Quality should comply with raw drinking water guidelines. 12 months minimum retention time of reclaimed water underground prior to withdrawal.

Reclaimed Water for Urban (Non Potable)

Reference Source	Type of Re-Use	Level of Treatment	Quality	Monitoring	Comments
(***Guidelines for Environmental Management - Use of Reclaimed Water* 2003)**	**Residential** Garden watering Toilet flushing Car washing Path/wall washing	Tertiary Pathogen reduction	pH 6.5-8.5 <2 NTU 1 mg/l Cl residual after 30 min, or equivalent indicator organism reduction to <10cfu/100ml	pH weekly BOD weekly Turbidity - daily continuous Coliforms daily	Shall include plumbing controls
(Anderson et al. 1993)	**Residential** Garden watering Closed system toilet flushing	Tertiary Pathogen reduction	Tertiary and Pathogen <10 E.coli per 100ml <10/5mg/L BOD / SS pH 6 – 9 <2 NTU Turbidity 1 mg/L Cl residual Nitrogen, Phosphorus 1 virus per 50 litres 1 protozoa per 50 litres	Weekly Disinfection Daily	Uncontrolled public access. Human food crops consumed raw. Open industrial systems with direct worker exposure potential.
(***Guidelines for Sewerage Systems - Use of Reclaimed Water* 2000)** **Note:** **It would seem this reference has been superseded by (*Queensland Guidelines for the Safe Use of Recycled Water* 2004)**	**Residential –** For open access urban re-use.	Tertiary Pathogen Reduction	Faecal Coliforms <1 in 100ml Coliforms <10 in 100ml (in 95% of samples) Virus - <2 in 50L Parasites <1 in 50L Turbidity <2 NTU pH 6-5 - 8.0 Free residual <0.5mg/L Salts & Nutrients	FC's to be taken 5 times a week. (subject to a reduction if approved by EPA) Virus & Parasites – Weekly	Collection at the outlet at the outlet from the water reclamation plant or defined entry point.

Reclaimed Water for Urban (Non Potable)

Reference Source	Type of Re-Use	Level of Treatment	Quality	Monitoring	Comments
(***Guidelines for Sewerage Systems - Use of Reclaimed Water* 2000)**	**Domestic and industrial** High to medium human contact	Tertiary – advance Tertiary	<10cfu/100ml Turbidity <2 NTU 1mg/L Cl residual pH 6 - 8.5	Weekly Disinfection continuous	High human contact and medium risk of ingestion. Alarm to activate if NTU exceeds 2 and supply shutdown if ntu>5 or chlorine residual falls below 1 mg/L
(***Guidelines for Sewerage Systems - Use of Reclaimed Water* 2000)**	**Toilet flushing closed systems** **(**Systems with no direct human contact with reclaimed water)	Tertiary Pathogen reduction	1 mg/L Cl residual or equivalent	Disinfection systems daily Coliforms weekly	Plumbing controls. For residential usage, Legionella controls and biocide dosing may be required.
(***Queensland Guidelines for the Safe Use of Recycled Water* 2004)**	**Municipal with uncontrolled public access.** Irrigation open spaces, parks, sportsgrounds, dust suppression, construction sites, and ornamental waterbodies.	Tertiary Pathogen reduction	pH 6.5 -8.5 <2 NTU 1 mg/L Cl residual or equivalent <10cfu /100ml	pH weekly BOD weekly Turbidity – daily continuos Disinfection systems daily Coliforms monthly	Colour reduction may be necessary for ornamental uses. Application rates limited to protect groundwater quality. Salinity should be considered for irrigation.
(***Queensland Guidelines for the Safe Use of Recycled Water* 2004)**	**Public Open Space-** Uncontrolled access above ground irrigation ,	Tertiary & Pathogen reduction	<10cfu/100ml Turbidity <2 NTU 1mg/L Cl residual pH 6 - 8.5	Weekly Disinfection continuous	High human contact and medium risk of ingestion. Alarm to activate if NTU exceeds 2 and supply shutdown if NTU>5 or chlorine residual falls below 1 mg/L
(***Guidelines for Sewerage Systems - Use of Reclaimed Water* 2000)**	**Public Open Space** Controlled access or sub-surface irrigation	Tertiary & Pathogen reduction	<1000 cfu /100ml SS mg/L 1mg/LChlorine residual pH 6-8 .5	Monthly Disinfection continuous	Low human contact , minimal risk of ingestion

Reclaimed Water for Urban (Non Potable) (cont'd)

Reference Source	Type of Re-Use	Level of Treatment	Quality	Monitoring	Comments
(***Guidelines for Environmental Management - Use of Reclaimed Water*** **2003)**	**Municipal with controlled public access** Irrigation open spaces, parks, sportsgrounds, dust suppression, construction sites, mines	Secondary Pathogen reduction	<1000 cfu/ 100ml	pH monthly SS monthly Disinfection systems daily Coliforms monthly	Application rates limited to protect groundwater quality. Salinity should be considered for irrigation. Irrigation during times of no public access. Withholding period nominally 4 hours or until irrigated area is dry.
(*Guidelines for Sewerage Systems - Use of Reclaimed Water* 2000)	**Municipal with controlled public access**	Secondary pathogen reduction	<1000 E.coli ,org/100ml, pH 6-9 <20/30mg/L BOD / SS Nitrogen and Phosphorus	Monthly Disinfection system daily	Restrict public access during irrigation period of 4 hours
(*Guidelines for Environmental Management - Use of Reclaimed Water* 2003)	**Agricultural** **Food production in direct contact.** Raw human food crops in direct contact with reclaimed water eg. via sprays, irrigation of salad vegetables	Tertiary Pathogen reduction	pH 6.5 – 8.5 1 mg/L Cl residual or equivalent. <2 NTU <10cfu/100ml	pH weekly Disinfection systems daily. Turbidity continuos Coliforms weekly	Application rates limited to protect groundwater quality. Salinity should be considered. A minimum of 25 days ponding treatment (e.g. sand filtration) for Helminth controls.
(*Guidelines for Sewerage Systems - Use of Reclaimed Water* 2000)	**Agricultural** : human food crops cooked / processed, grazing for livestock	Secondary – pathogen Reduction (including Helminth reduction for cattle grazing)	<1000 E.coli ,org/100ml, pH 6-9 <20/30mg/L BOD / SS Nitrogen and Phosphorus	Monthly Disinfection system daily	Nutrient reduction – Application rates control to protect groundwater, soils and surface water quality

Reclaimed Water for Urban (Non Potable) (cont'd)

Reference Source	Type of Re-Use	Level of Treatment	Quality	Monitoring	Comments
(***Queensland Guidelines for the Safe Use of Recycled Water* 2004)**	**Agricultural** **Food production not in direct contact.** Raw Human food crops not in direct contact with reclaimed water (edible product separated from contact with effluent, eg, by peel, sue of trickle irrigation) or crops sold to consumers cooked or processed.	Secondary Pathogen reduction	pH 6.5 -8.5 <1000 cfu/100ml	pH weekly BOD weekly SS weekly Coliforms weekly	Application rates limited to protect groundwater quality. Salinity should be considered. Crops must be cooked (>70C for 2 minutes), commercially processed or peeled before consumption.
(***Guidelines for Sewerage Systems - Use of Reclaimed Water* 2000)**	**Food Crops and retail nurseries** Food crops consumed raw	Tertiary - Advance Pathogen reduction	<10 cfu/100ml Turbidity NTU 2 Total Cl 1.0mg/L 6-8.5	Removal of viruses and protozoa E *coli* weekly Turbidity continuous Chlorine daily pH weekly	High human contact with medium risk of ingestion. Alarm to activate if NTU exceeds 2 and supply shutdown if NTU>5 or chlorine residual falls below 1 mg/L
(***Guidelines for Sewerage Systems - Use of Reclaimed Water* 2000)**	**Food Production (Pasture and Fodder)** Grazing animals except pigs and dairy animals, ie, cattle, sheep and goats.	Secondary Pathogen reduction	pH 6.5- 8.5 coliforms <1000cfu/100ml	pH weekly SS weekly Coliforms weekly Disinfection systems daily	Application rates limited to protect groundwater quality. Withholding period of nominally 4 hours for irrigated pasture. Drying or ensiling of fodder. Helminth controls.

Reclaimed Water for Urban (Non Potable) (cont'd)

Reference Source	Type of Re-Use	Level of Treatment	Quality	Monitoring	Comments
(***Queensland Guidelines for the Safe Use of Recycled Water* 2004)**	**Agricultural Food Production** Pasture and fodder for dairy animals (with withholding period)	Secondary Pathogen reduction	pH 6.5- 8.5 <1000 cfu / 100ml	pH weekly SS weekly Coliforms weekly	Application rates limited to protect groundwater quality. Withholding period of 5 days for grazing animals. Drying or ensiling of fodder and Helminth controls.
(*Guidelines for Sewerage Systems - Use of Reclaimed Water* 2000)	**Irrigation pasture/fodder and agricultural wash down.** Pasture and fodder for dairy animals (with withholding period)	Secondary Pathogen reduction	<1000 cfu / 100ml SS 30mg/L Disinfection may be required Ph 6- 8.5	E coli weekly SS, pH weekly	Helminth controls
(***Queensland Guidelines for the Safe Use of Recycled Water* 2004)**	**Agricultural Food Production** Pasture and fodder for diary animals (without withholding period). Drinking water (all stock except pigs). Washdown water for dairies	Secondary Pathogen reduction	pH 6.5 – 8.5 <1000cfu / 100ml	Ph weekly SS weekly Disinfection systems daily	Application rates limited to protect groundwater quality. No withholding period. Helminth controls.
(*Guidelines for Sewerage Systems - Use of Reclaimed Water* 2000)	**Irrigation pasture/fodder and agricultural wash down.** Pasture and fodder for dairy animals (without withholding period)	Secondary Pathogen reduction	<100 cfu / 100ml SS 30mg/L Disinfection may be required Ph 6- 8.5	E coli weekly SS, pH weekly	Medium human contact
(*Guidelines for Sewerage Systems - Use of Reclaimed Water* 2000)	**Non food crops** Silviculture, turf and cotton etc.	Secondary Pathogen reduction	pH 6.5 – 8.5 <10,000 cfu/100ml	pH weekly BOD weekly SS weekly	Application rates limited to protect groundwater quality. Restricted public access. Withholding period of nominally 4 hours or until irrigated area is dry.

Reclaimed Water for Urban (Non Potable) (cont'd)

Reference Source	Type of Re-Use	Level of Treatment	Quality	Monitoring	Comments
(***Queensland Guidelines for the Safe Use of Recycled Water* 2004)**	**Aquaculture** **Non-human food chain**	Secondary Pathogen reduction Maturation ponds (5 days retention time)	Coliforms <10,000 cfu / 100ml	pH weekly SS weekly Coliforms weekly Disinfection systems daily	Salinity Controls TDS <1000mg/L <10% change in turbidity (seasonal mean conc.) Dissolved oxygen controls may be required for fish zooplankton.
(***Queensland Guidelines for the Safe Use of Recycled Water* 2004)**	**Aquaculture -** **Human food chain**	Tertiary – advance Tertiary	<10cfu/100Ml Turbidity <2 NTU 1mg/L Cl residual pH 6 - 8.5	Weekly Disinfection continuous	High human contact and medium risk of ingestion. Alarm to activate if NTU exceeds 2 and supply shutdown if NTU>5 or chlorine residual falls below 1 mg/L
(***Guidelines for Sewerage Systems - Use of Reclaimed Water* 2000)**	**Aquaculture** **Non-human food chain**	Secondary Pathogen reduction	<1000 cfu / 100ml SS 30mg/L Disinfection may be required Ph 6- 8.5	E coli weekly SS, pH weekly	Low human contact
(***Guidelines for Sewerage Systems - Use of Reclaimed Water* 2000)**	**Passive Recreational** Ornamental waterbodies with no contact	Secondary Pathogen reduction	Coliforms <1000 cfu/100ml	Ph weekly SS weekly Coliforms weekly Disinfection system daily	Surface films to be absent. Minimised nutrient concentration (i.e. eutrophication). Restriction on access.
(***Guidelines for Sewerage Systems - Use of Reclaimed Water* 2000)**	**Environmental** Stream augmentation	Secondary (site specific) Pathogen reduction	Site specific	Site specific depending on water quality requirement	Receiving water quality requirements to be considered. State Health and Environment regulations apply. Temperature controls. Consider nutrient status re. Risk of eutrophication.

Reclaimed Water for Urban (Non Potable) (cont'd)

Reference Source	Type of Re-Use	Level of Treatment	Quality	Monitoring	Comments
(***Guidelines for Sewerage Systems - Use of Reclaimed Water* 2000**)	**Industrial** **Closed system** Cooling water	Process specific Secondary	Site specific Site specific	Site specific depending on water quality requirement and end use.	Treatment may be required to prevent scaling corrosion, biological growth, fouling and foaming.
(***Guidelines for Environmental Management - Use of Reclaimed Water* 2003**)	**Industrial** **Open system** Primary contact possible (Mines, dust suppression)	Secondary Pathogen reduction	Site specific Coliforms <1000 cfu/100ml	pH weekly BOD weekly SS weekly Coliforms weekly Disinfection daily	Treatment may be required to prevent scaling, corrosion, biological growth, fouling and foaming. Windblown spray minimised.
(***Queensland Guidelines for the Safe Use of Recycled Water* 2004**)	**Industrial systems:** with no potential worker exposure	Secondary pathogen reduction	<1000 E.coli ,org/100ml, pH 6-9 <20/30mg/L BOD / SS Nitrogen and Phosphorus	Monthly Disinfection system daily	Restrict public access during irrigation period of 4 hours
(***Queensland Guidelines for the Safe Use of Recycled Water* 2004**)	**Industrial Purposes** **Open systems / Fire Fighting**	Tertiary - Advance Pathogen reduction	<10 cfu/100ml Turbidity NTU 2 Total Cl 1.0mg/L 6-8.5	Removal of viruses and protozoa E *coli* weekly Turbidity continuous Chlorine daily pH weekly	High human contact with medium risk of ingestion. Alarm to activate if NTU exceeds 2 and supply shutdown if NTU>5 or chlorine residual falls below 1 mg/L
(***Guidelines for Sewerage Systems - Use of Reclaimed Water* 2000**)	**Environmental /Recreational purposes (no human contact)**	Secondary Pathogen reduction	<1000 cfu / 100ml SS 30mg/L Disinfection may be required Ph 6- 8.5	E coli weekly SS, pH weekly	Low human contact Site specific depending on the receiving water quality

Appendix B: ANZECC Water Quality Guidelines for the Protection of Aquatic Ecosystem Health for Fresh and Marine Waters.

ANZECC - Water Quality Guidelines for Fresh Waters and Marine/Estuarine Waters		
Water Quality Parameter	**Fresh Waters**	**Marine/Estuarine Waters**
PH	6.5 - 8.0	7.0-8.5
Conductivity	<0.3ms/cm	NR
Turbidity	<6ntu	<10ntu
Dissolved Oxygen	<85 or >110 %saturation	<80 or >110 %saturation
Temperature	>11.7 ^{o}C or <20.1 ^{o}C	NR
Salinity	NR	NR
Oxidised nitrogen (NOX)	<0.04mg/L	<0.015mg/L
Ammonia	<0.02mg/L	<0.015mg/L
Total Nitrogen	<0.350mg/L	<0.3mg/L
Total Phosphorus	<0.025mg/L	<0.03mg/L
Suspended solids	10mg/L	NR
Chlorophyll a	<3 *ug*/l	<4 *ug*/l

Source:(*Australian and New Zealand Guidelines for Fresh and Marine Water Quality* 2000)

NR - Not recommended

Appendix C: List of Acronyms

Term	Definition
ABS	Australian Bureau of Statistics
ANZECC	Australian and New Zealand Environment and Conservation Council
AUH	Artificial Units of Habitats
BASIX	Building Sustainability Index
BCC	Brisbane City Council
BOM	Bureau of Meteorology
CICM	Centre for Integrated Catchment Management
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CMA	Catchment Management Authorities
CRC	Cooperative Research Centre
CSD	Commission on Sustainable Development
DCP	Development Control Plan
DEUS	Department of Energy, Utilities and Sustainability
DEC	Department of Environment and Conservation
DEH	Department of Environment and Heritage
DEWR	Department of Environment and Water Resources
DSE	Department of Sustainability and Environment
DLWC	Department of Land and Water Conservation
DPIF	Department of Primary Industries and Fisheries
DPWS	Department of Parks and Wildlife Service
DRASTIC	Depth, Recharge, Aquifer, Soil, Topography, Impact, Conductivity
EUM	End Use Model
ESD	Ecologically Sustainable Development
EPA	Environmental Protection Authority
GDE	Groundwater Dependent Ecosystems
GIS	Geographical Information Systems
GPT	Gross Pollutant Trap
HSLEP	Hornsby Shire Local Environmental Plan
HSC	Hornsby Shire Council
ICLEI	International Council for Local Environmental Initiatives
IWCM	Integrated Water Cycle Management
KPI	Key Performance Indicator
LGA	Local Government Area
LGSA	Local Government and Shires Associations
MUSIC	Model for Urban Stormwater Improvement Conceptualisation
NASA	National Aeronautical Space Agency
NSESD	National Strategy for Ecologically Sustainable Development
NWQMS	National Water Quality Management Strategy
RGMC	Regional Groundwater Management Committee
SAWRC	South African Water Research Commission
SCCG	Sydney Coastal Councils Group
SET	Sedimentation Erosion Tables
STP	Sewage Treatment Plant
STWCMS	Sustainable Total Water Cycle Management Strategy
TBL	Triple Bottom Line
TNS	The Natural Step
TWP	Technical Working Party
UNESCO	United Nations Educational, Scientific and Cultural Organisation
USEPA	United States Environmental Protection Agency
USGCRP	United States Global Change Research Program
USLE	Universal Soil Loss Equation
USNSF	United States National Science Foundation
WCSC	Water Cycle Steering Committee
WSUD	Water Sensitive Urban Design