A Preliminary Framework for Externality Assessment and Economic Valuation for Total Water Cycle Management: An Application to the Moreton Bay Regional Council Planning Process

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The Urban Water Security Research Alliance (UWSRA) is a $50 million partnership over five years between the Queensland Government, CSIRO's Water for a Healthy Country Flagship, Griffith University and The University of Queensland. The Alliance has been formed to address South East Queensland's emerging urban water issues with a focus on water security and recycling. The program will bring new research capacity to South East Queensland tailored to tackling existing and anticipated future issues to inform the implementation of the Water Strategy.

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FOREWORD

Water is fundamental to our quality of life, to economic growth and to the environment. With its booming economy and growing population, Australia's South East Queensland (SEQ) region faces increasing pressure on its water resources. These pressures are compounded by the impact of climate variability and accelerating climate change.

The Urban Water Security Research Alliance, through targeted, multidisciplinary research initiatives, has been formed to address the region's emerging urban water issues.

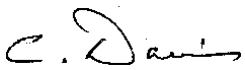
As the largest regionally focused urban water research program in Australia, the Alliance is focused on water security and recycling, but will align research where appropriate with other water research programs such as those of other SEQ water agencies, CSIRO's Water for a Healthy Country National Research Flagship, Water Quality Research Australia, eWater CRC and the Water Services Association of Australia (WSAA).

The Alliance is a partnership between the Queensland Government, CSIRO's Water for a Healthy Country National Research Flagship, The University of Queensland and Griffith University. It brings new research capacity to SEQ, tailored to tackling existing and anticipated future risks, assumptions and uncertainties facing water supply strategy. It is a $50 million partnership over five years.

Alliance research is examining fundamental issues necessary to deliver the region's water needs, including:

- ensuring the reliability and safety of recycled water systems.
- advising on infrastructure and technology for the recycling of wastewater and stormwater.
- building scientific knowledge into the management of health and safety risks in the water supply system.
- increasing community confidence in the future of water supply.

This report is part of a series summarising the output from the Urban Water Security Research Alliance. All reports and additional information about the Alliance can be found at http://www.urbanwateralliance.org.au/about.html.



Chris Davis
Chair, Urban Water Security Research Alliance

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LIST OF ACRONYMS

BNR	Biological Nutrient Removal
ABS	Australian Bureau of Statistics
CBA	Cost-benefit Analysis
CEA	Cost-Effectiveness Analysis
CSIRO	Commonwealth Scientific and Industrial Research Organisation
eWater CRC	eWater Cooperative Research Centre
GHG	Greenhouse Gases
GU	Griffith University
LCA-IM	Life Cycle Analysis – Integrated Modelling project of the UWSRA
MCA	Multi-Criteria Analysis
ML	1 megalitre, or 1 million litres
QWC	Queensland Water Commission
SEQ	South East Queensland
SEQ-RP	South East Queensland Regional Plan
SEQWS	South East Queensland Water Strategy
SWM	Sustainable Water Management
TBL	Triple bottom line
TEV	Total Economic Value
UQ	University of Queensland
UWSRA	Urban Water Security Research Alliance
WGM	Water Grid Manager
WTP	Willingness to Pay
WWTP	Wastewater Treatment Plants

EXECUTIVE SUMMARY

Purpose and Aims

The primary aim of this report is to develop a method guide and provide indicative supporting data for the identification, valuation and incorporation of externalities for water servicing options. This capability is essential for the more complete "triple bottom line" (TBL) accounting and decision-making processes that will increasingly become the standard in project assessment. Although the report is specifically aimed at providing the initial scoping information for the Moreton Bay Regional Council (MBRC), the case study approach is intended to inform the extended application of externality analysis and TBL accounting to any related water servicing planning context. The analysis is pivoted on a total water cycle management (TWCM) approach, which has been adopted as the underlying framework for water management in the South East Queensland (SEQ) region.

The study builds upon externality identification and valuation estimates, proposed simple externality analysis methodology, and assessment of the these aspects in decision-making in the two previous supporting reports by the authors – see Daniels, Porter *et al.* (2012) and Daniels, Porter and Bodsworth (2012).

The specific aims of this report follow the analytical focus by key UWSRA partners on the assessment and application of TWCM to the Moreton Bay Regional Council (MBRC) case study. It presents the results of a more in-depth analysis and valuation of externalities relevant to the specific regional context and water servicing options proposed for the MBRC. Hence, a clear focus is upon the informed assessment of economic, environmental and social externalities associated with TWCM options and their integration into urban development and broader sustainability planning processes.

The report does not comprise a complete extended externality analysis of TWCM water servicing options considered for the MBRC. The generation of the biophysical and other social and economic quantitative externality data required for economic valuation of additional effects (to the nutrient, energy and greenhouse gas (GHG) emission impacts covered in other related studies) has been beyond the resources of this small project. The purview of the report has been limited to: (1) scoping for the full range of externalities that are likely to be relevant in the study setting; (2) the review and compilation of existing quantitative and valuation estimates of these externalities in other studies; and (3) discussion of initial context-relevant considerations, in order to proceed with a complete externality of TBL accounting analysis in the case study setting.

The process of the initial measurement of biophysical and other social and economic quantitative externality data required for assessing their significance and economic value is a major area recommended for additional R&D. The identification of relevant potential externalities and their indicative economic values is demonstrated in this report. However, the next essential step is to investigate a cost-effective and systematic process for providing context-specific data. Comprehensive TBL accounting with the full analysis of significant social, economic and environmental impacts (or constraints) will be the norm in project assessment within a decade. Many lessons have been learnt to date and increasing social, corporate and environmental accountability, and growing energy and other resource vulnerability will reinforce this trend.

Study Context and Scope

The report focuses specifically on the Moreton Bay Regional Council (MBRC) in SEQ as the primary case study region. This is consistent with the MBRC TWCM Plan that has been developed on the basis of the *TWCM Planning Guideline for South East Queensland* (WBD, 2010a) and to satisfy requirements set out in the *Environmental Protection (Water) Policy (2009)*.

The extended externality analysis completed for this report is intended to pave the way for future assessments of major water servicing options; providing a preliminary framework and indicative data to expand the evaluation beyond a relatively narrow range of water quality and alternate water supply and water savings targets. The existing major TWCM planning document for the MBRC is essentially a cost-effectiveness analysis (CEA) restricted, in terms of its impact scope, to the examination of the capital and operating costs to achieve alternate water supply and pollutant load reduction targets (and with some consideration of GHG emissions associated with total supply in each catchment). This has been a reasoned and practical response to the direct requirements of the Environmental Protection (Water) Policy (2009). The MBRC TWCM Plan analysed three water management scenarios for 2011-2031 and their constituent "solution sets" for each catchment in the MBRC. The profile of external effects (welfare impacts of the scenarios upon society, beyond those in the direct market or financial transactions) for the CEA only covers the water quality issues of total suspended solids (TSS), total phosphorus (TP) and total nitrogen (TN) and GHG emissions.

Consideration of a more extensive range of relevant externalities will be intrinsic to future, more comprehensive, TWCM perspectives. Both notions (externalities and TWCM) are predicated on the existence of strong "ecological" relations, and the need to trace and understand the interconnections and flow-on effects that will inevitably have significant consequences for the net community economic and social welfare outcomes of major interventions related to water management.

Method and Key Findings

The report provides three main sets of results:

(1) The detailed identification of external effects likely to be associated with alternate water options for the Moreton Bay Regional Council (Chapter 3)

Firstly, the report builds upon the earlier background research in Daniels *et al.* (2012) to provide an updated and more extensive review and compilation of the external costs and benefits of the ***three general options*** that are considered central in the TWCM planning process in the MBRC – *wastewater recycling to urban and industry uses, stormwater harvesting and rainwater tanks (in greenfield sites).* The sources of information for this review include technical descriptions of each water servicing option, more specific externality studies (especially those related to water), and relevant background information on the MBRC case study context.

(2) The compilation of an extensive range of economic valuation estimates for the relevant set of identified water-related externalities (Chapter 4)

The second major set of results is a detailed compilation of existing monetary valuation estimates for each of the external effects from the identification process in (1). These valuations were gleaned from a diverse range of existing environmental economic research. Details of the relevant economic valuation techniques (and their links to total economic value (TEV) types and the externality effects) have been provided in the previous two reports (see Daniels *et al.,* 2012; Daniels, Porter, and Bodsworth, 2012). The original estimates have been converted to 2010 Australian dollar equivalents in order to facilitate ready comparison. They are presented for use in a general "transfer benefits" sense where the estimates can be considered as indicative and subsequently used with qualification or with modification based on known local conditions. Of course, they can be rejected or simply used as comparative measures when primary research is possible or required given unique or very different contextual settings.

(3) An example application of the externality economic valuations based on total GHG emissions for the three management scenarios across the MBRC catchments (Chapter 4)

The main externality identification tables provide major guides and information feeds for Step 2 of the simple externality analysis outlined in Daniels, Porter and Bodsworth (2012) and the economic valuation estimates in Chapter 4 provide the major data source for Step 4. Step 1 is completed in the

initial strategic planning process and Steps 3-5 require scientific research and technical understanding to identify biophysical and other quantitative dose-response relations associated with the water servicing option, or "solution set" under study.

There are good reasons why data for more extended externality analyses are limited – the required research is often resource-intensive and of uncertain cost-effectiveness. However, relevant conceptual, methodological and data capabilities (including accumulated knowledge and database feeds) are growing strongly and will continue to facilitate better analyses in future.

The major externalities relating to stormwater harvesting, rainwater tanks and wastewater recycling in the MBRC area have been identified in the text boxes below.

STORMWATER HARVESTING

- Reduction in pollution, decreased nutrient to waterways from stormwater runoff, leading to downstream economic, social and ecosystem benefits (Collection and Treatment Stages)
- Provision of recreational spaces (when incorporating wetlands or ponds). (Storage Stages)
- Enhanced flood mitigation. (Storage Stages)
- Possible increases in surrounding property values, stemming from amenity benefits of water bodies. (Storage Stages)
- Potential health concerns – e.g. mosquito breeding sites, pathogens, organic chemicals, heavy metals; and drowning hazards. (Storage Stages)
- Fauna and flora benefit through aquatic habitat provision. (Storage Stages)
- Chemicals usage for treatment and product water distribution
- More energy-intensive than conventional mains supply
- Risk of soil contamination (if used for irrigation) (Use Stages)
- Risk of cross-contamination and consequent illness. (Use/ Distribution Stages)
- Decreased mains water use, which will offset externalities from those sources and may defer the need for additional water infrastructure. (Use Stages)

RAINWATER TANKS

- Reduction in pollution to waterways from stormwater runoff, leading to downstream economic, social and ecosystem benefits (Collection and Treatment Stages)

Comparatively higher energy usage than reticulated mains water (mostly due to inefficient pump systems). (All Stages)

- Higher GHG emissions than reticulated water. (All Stages)
- Enables gardening and home food production to occur despite drought conditions and water restrictions (this leads to amenity and recreational benefits). (Use/Distribution Stages)
- Decreased mains water use, which will offset externalities from those sources and may defer the need for additional water infrastructure. (Use Stages)
- Decreased pressure on drainage infrastructure in flood events. (Collection and Storage Stages)
- Potential contamination risk leading to negative health consequences. (Storage and Use Stages)
- Possible mosquito breeding site if poorly maintained. (Storage Stages)
- Disposal of old tanks is a potential source of pollution and environmental and health contamination risk (Disposal Stages)

WASTEWATER RECYCLING-

- Reduced pollution of receiving waters. (Collection and Treatment Stages)
- Additional water resource available to drought constrained farmers and other industries. (Collection and Use Stages)
- Risk of soil contamination if used for irrigation. (Use Stage)
- Contamination risks and associated health concerns. (Treatment and Use, Distribution Stages)
- Low levels of community acceptance and increased social conflict for 'high-contact' uses (Use Stage)
- Agricultural reuse has potential to reduce the need for synthetic fertiliser use (Use Stage)
- Increased capacity for maintenance of 'green spaces' throughout droughts – amenity and recreational benefits. (Use Stage)
- Disposal of concentrate (a by-product) may lead to environmental degradation and/or high transport requirements
- Enables gardening and home food production to occur despite drought conditions and water restrictions (this leads to amenity and recreational benefits). (Use/Distribution Stages)
- Power and chemicals use for treatment and product water (Treatment stage)

A tentative assessment shows that the $23/tonne valuation for GHG emissions externalities does not have a major impact in relation to the net present value (NPV) of the capital and operating costs associated with each MBRC catchment management scenario (and their component solution sets). For the change in CO_2 equivalent emissions required for the NPV expenditure to implement the proposed management scenarios, the externality costs of GHG emissions are rarely more than 2% of the

indicative NPV costs. The valuations of total CO_2 emissions associated with the management scenarios are more significant and can be equal to up to 82% of the indicative NPV costs (for example, for Brisbane Coastal Scenario 1) but are more often around 10-20% with many below 5%.

Conclusions, Recommendations and Policy Considerations

Together, the description of externalities linked to specific water options and the detailed set of monetary valuation estimates provide a useful resource for researchers and planners – one which can feed information on the extent of "trade-offs" involved, into most decision-making frameworks for future water supply planning in the Moreton Bay Regional Council. This includes decision-making tools such as multiple criteria assessment and cost-benefit analysis (see Daniels, Porter and Bodsworth, 2012).

The ability to analyse an expanded range of external effects requires adequate knowledge of the main relevant interconnections within and between environmental and socioeconomic systems. It also needs, as a basic pre-requisite, the fundamental biophysical or at least quantitative measures as per Step 3 of the SEXTAN methodology outlined in Technical Report 81 (Daniels, Porter and Bodsworth, 2012); that is, "for each option in the scenario, the biophysical or socioeconomic (non-monetary) quantification of each externality generated per unit output of required water quality from that option." To compare the full social costs and benefits of proposed management scenarios, this information is required for: (1) existing water servicing conditions; and (2) new solution set mix/management scenarios. Unfortunately, few data are available in the study setting beyond the financial costs of achieving target outcomes.

It is recommended that a pilot project be completed to quantify and value a more complete range of TBL impacts (as outlined in this report). This would be best applied for one of the catchment management scenarios selected via the combined Cost-effectiveness analysis (CEA) and Multi-Criteria Analysis (MCA) process in BMT WBM (2012). The study would need to take into account specific site technical, geographic, operation and socio-demographic conditions. This report has provided a useful basis for a more detailed study of this kind. Potential benefits include the ability to monitor, *ex post*, the efficacy of existing water servicing option evaluation methodologies, and to pave the way to better, more comprehensive TBL assessments of the true net community welfare impacts of these critical, and very expensive, societal investments.

CEA, as implemented in the current MBRC TWCM Plan, provides an effective and efficient means of attempting to balance a limited range of (relatively important and priority) immediate objectives. Cost-effectiveness is undoubtedly a major factor to consider in project evaluation. However, is not conducive to TBL accounting, sustainability goals and the depth of analysis required for maximising net community welfare from major resource, utility and infrastructure investment decisions. Existing assessments reflect the lack of knowledge and data on the interactions and external effects of major solution sets (e.g. wastewater recycling) that must be taken into account for efficient use and overall community well-being. Although the required information can be costly to acquire, well-researched and cost-effective pre-emptive awareness and knowledge of potential spill-over and other unintended effects of projects is vital and can have an enormous impact on choices and their resulting net community benefit.

There is marked progress in the tools and capabilities, and environmental economic accounting systems to better assess (quantify and monetise) the intricate web of effects through the economy, and between the economy and nature. Further research into major impact assessment and valuation data gap areas such as ecosystem services, health, community understanding and acceptance, environmental flows and water quality, and land use effects will greatly enhance these capabilities.

1. INTRODUCTION

Urban development has a significant influence upon natural hydrological cycles, with impacts such as alterations to groundwater levels, pollution and littering of waterways, modified nutrient loads and changed flow patterns (Naji and Lustig, 2006, p.196). Chanan and Woods (2006) note the increasing pressures of such development in the Australian state of New South Wales:

> *The consequences of this anthropogenic manipulation on the hydrologic cycle are gradually becoming evident. Rivers, lakes, and wetlands worldwide are undergoing serious decline in health. Important life-sustaining ecological functions that these natural ecosystems provide, such as water purification, flood protection, and provision of habitats for wildlife including fish and waterfowl, are being lost." (p.12)*

The typical effects of urban development upon the natural water cycle include a diverse range of impacts (often unintended and non-marketed) associated with greater water consumption, and hence supply and wastewater, changes to environmental flows, and also runoff, peak flows and soil erosion and sediment impacts. Some of the potential effects are illustrated in Figure 1. As water is a finite and precious resource with profound interconnections to a host of biophysical processes and human interventions, it is essential that natural water cycles and waterways be preserved in a way that maintains their critical ecosystem services as well as their direct inputs to industry and households in the economy.

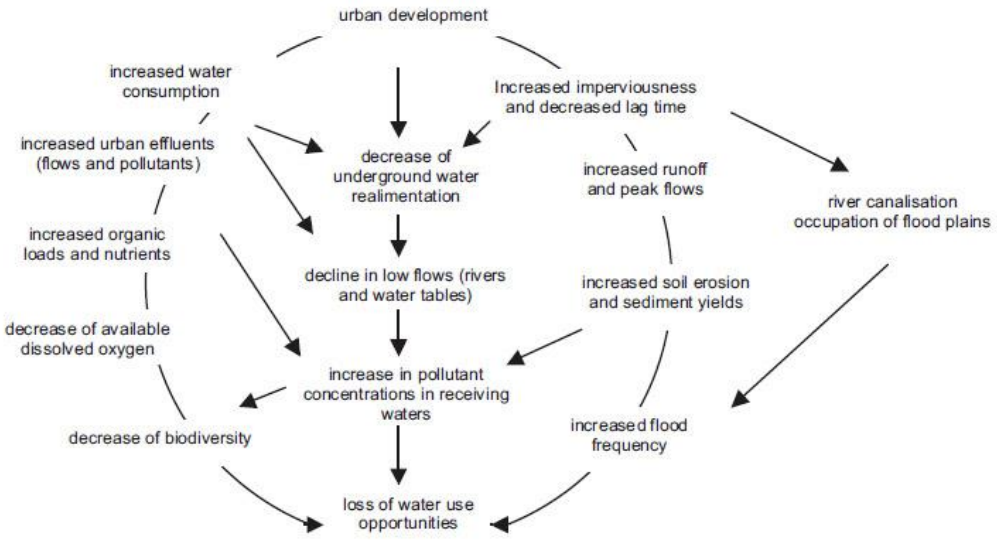


Figure 1: Effects of urbanisation on the water cycle.

Source: Chocat *et al.* (2007, p.275)

Total Water Cycle Management (TWCM) constitutes a move away from the traditional water management paradigm of just creating more supply (for example, building new dams). Rather, it seeks potential, often innovative, supply or water balance options with a focus on natural water cycles and, often, decentralised approaches (Chanan and Woods, 2006; Chocat *et al*, 2007). TWCM is relevant to many natural and human geographic levels but a defining feature tends to be its "whole of catchment" approach that engenders participatory and highly-informed decision-making and planning from the involvement of all of the stakeholders linked to the healthy and sustainable management of catchments (Chanan and Woods, 2006 p.15). Many of the methods proposed in TWCM are capable of providing reliable water supply, and reducing or minimising damage to catchment hydrology (Naji and Lustig, 2006). TWCM adopts a balanced approach that combines decentralised and centralised supply sources in a way that "fits" natural hydrological cycles and uses sustainable water planning practices and

methods. Two supply options that are popular within a broader TWCM framework are options involving wastewater recycling and stormwater harvesting (Chocat *et al*, 2007).

The specific directive for TWCM in the case study area of the Moreton Bay Regional Council (MBRC) is a legislative in nature and comes from the Environmental Protection (Water) Policy 2009 Subordinate Legislation 2009 No. 178 made under the *Environmental Protection Act 1994, Queensland Government*. As described in Water By Design (2010, p.16), this policy requires local governments above a certain population size to implement TWCM plans that must include provision for:

(a) the collection, treatment and recycling of waste water, stormwater, ground water and other water sources; and
(b) the integration of water use in its area.

In their plans, local governments must also consider:

(a) a strategy for demand management for water in its local government area;
(b) ways to increase recycling of waste water and stormwater for purposes including, for example, industrial or agricultural purposes;
(c) ways to use recycled waste water;
(d) opportunities for stormwater harvesting for use as a water source;
(e) the impacts of existing and future land use in the area on water cycle management, including the following:
    (i) impacts of the use on the natural flow of waters;
    (ii) impacts of the use on water quality objectives for waters;
    (iii) the risks to drinking water supplies caused by the use; and
(f) a forecast of the water supply requirements for the area.

At a more general level, TWCM tends to be guided by at least three key principles. Firstly, the efficient use of water is a fundamental maxim. Secondly, there is a pronounced recognition of stormwater and wastewater as valuable water resources that have key roles under the integrated, bioregional, catchment, and sustainability perspectives inherent to TWCM. Thirdly, it embraces the importance of matching demand with the supply of appropriate water quality available from various sources (such as stormwater, rainwater, greywater, and wastewater) (Chanan and Woods, 2006).

Thus, a TWCM approach is likely to involve consideration of:

- the reuse of **reclaimed wastewater** (for pollution prevention, non-potable water supply);
- integrated **stormwater, groundwater,** water supply and **wastewater-based management** (water supply, flow management, water and landscape provision, substituting sub-potable water sources where feasible, and protection of downstream areas against urban impacts); and
- **water conservation**-based approaches (efficient water use, reduced water demand for landscape irrigation, and substitution of industrial processes with reduced water demands) (Chocat *et al*, 2007).

At a broader, regional level, a TWCM approach is also embraced in the *South East Queensland Regional Plan* – the broader, comprehensive "master" plan designed to guide growth and development in the region. Hence, TWCM involves "the integration of land use and infrastructure planning across SEQ as a whole and for major development areas, local areas and specific sites" (QWC, 2009 p 27). Similarly, water management in the project study area of the Moreton Bay Regional Council is guided by the *South East Queensland Water Strategy* (SEQWS) which provides an overall blueprint for the maintenance of the region's water security into the future. The strategy asserts that water management should now proceed only within a "total water supply framework" which also embraces the fundamental importance of taking a total water cycle approach for effective and sustainable water planning (QWC, 2009 p 27). Specifically, the SEQWS aims to:

- use and manage water within regional land limitations
- incorporate potential demand management options
- consider all of the available options: including purified recycled water and stormwater schemes
- assign new design standards for developments and
- recognise the importance of catchment management in the protection of public and ecosystem health.

1.1. Report Aims

The primary aim of this report is to develop, collate and adapt methods and data for the identification, measurement, valuation and incorporation of externalities, in order to effectively support full triple bottom line (TBL) accounting and decision-making for water servicing options considered for TWCM approaches now adopted for the SEQ region.[1] The report takes a specific focus upon the Moreton Bay Regional Council (MBRC) as the primary case study region completed for the Queensland Water Commission (QWC) in 2012. As noted, the MBRC TWCM Plan has been developed on the basis of the *TWCM Planning Guideline for South East Queensland* (Water by Design, 2010a) and to satisfy requirements as laid out in the *Environmental Protection (Water) Policy (2009)*.

In view of the specific directives of the Environmental Protection (Water) Policy 2009, the research underlying the development of the MBRC TWCM Plan has involved a cost-effectiveness analysis (CEA). It analyses three main scenarios for 2011-2031 and their constituent "solution sets" for each catchment in the MBRC. The CEA has been restricted, in terms of its impact scope, to the examination of the capital and operating costs to achieve alternate water supply and pollutant load reduction targets (and with some consideration of greenhouse gas (GHG) emissions associated with total supply in each catchment). Hence, the profile of external effects (welfare impacts of the scenarios upon society, beyond those in the direct market or financial transactions) for the CEA only covers the water quality issues of total suspended solids (TSS), total phosphorus (TP) and total nitrogen (TN), and GHG emissions.[2] The study has also included some additional social, economic and environmental impacts using a multi-criteria analysis (MCA). Overall, the approach does not claim to represent (and does not constitute) a TBL accounting study. The range of potential effects is assessed only as a rather generalised and limited set of "performance targets" (see Table 4-E of BMT 2012).

Arguably, consideration of a more extensive range of relevant externalities will be intrinsic to future, more comprehensive, TWCM perspectives. Both notions (externalities and TWCM) are predicated on the existence of strong "ecological" relations, and the need to trace and understand the interconnections and flow-on effects that will inevitably have significant consequences for the net community economic and social welfare outcomes of major interventions related to water management. Studies for other major societal investments have shown that full social cost-benefit analysis can yield very different assessment so the relative attractiveness of alternative options (for example, see Roth and Ambs (2004) for electricity power generation).

This close link between the TWCM perspective and a focus upon analysing externalities is implicit in the *Total Water Cycle Management Guideline for South East Queensland* (Water by Design 2010, p.3) which states that "TWCM recognises that all elements of the water cycle are interdependent – a decision made in one part of the cycle affect other parts of the cycle. All elements of the water cycle should be considered – separately and in combination. TWCM also requires integration of infrastructure planning with land use planning". Adoption of a life cycle assessment perspective is also essential to ensure comprehensive coverage of the cost and benefits of options under evaluation.

[1] Externalities occur when one person's consumption or production behaviour affects that of another without any compensation. Compensation (paying for a good or service and receiving income for production inputs) usually occurs as a consensual agreement between buyer and seller in the marketplace. In theory, if decision options can be fully assessed in terms of both market and externality effects across society and over time, there is enhanced potential for making choices that effectively increase well-being or at least make good use of society's limited resources.

[2] The restricted nature of CEA as a tool for TBL accounting of major societal investments has been outlined in Daniels, Porter and Bodsworth (20120).

The general goal of collating relevant valuation data estimates and valuation and analysing them within a decision-making framework has guided the two previous supporting reports by the authors – see Daniels, Porter *et al.* (2012) and Daniels, Porter and Bodsworth (2012).

The specific aims of this report follow the analytical focus of key UWRSA partners on the assessment and application of TWCM to the Moreton Bay Regional Council (MBRC) case study. It presents the results of a more in-depth analysis and valuation of externalities relevant to the specific regional context and water servicing options proposed for the MBRC. Hence, a clear focus is upon the informed assessment of economic, environmental and social externalities associated with TWCM options, and their integration into urban development and broader sustainability planning processes.

Initial research into appropriate TWCM solution sets and their component options for the MBRC was published in 2010 (see BMT WBM (2010)). This report identified a series of alternate TWCM option solution sets ("S5", "S6" and so forth). The preferred options selected for more intensive analysis included stormwater harvesting (S10), and wastewater recycled to urban and industrial uses (S5 and S6) and the solution set associated with "Future development meets QDC alternative water supply mandate" which, in practice, essentially involves the implementation of rainwater tanks in greenfield development sites. The aim is to enhance the information provided for both the evaluation phase and ongoing water management decision-making needs, by providing a more extensive and comprehensive economic assessment of the broad range of social, economic and environmental externalities related to the wastewater recycling, stormwater harvesting and rainwater tank solution sets (within the context of the MBRC).

Access to detailed information about the externalities of water servicing options, and their estimated cost or benefit values, will be an increasingly important resource for water researchers, policy-makers and practitioners (Retamal *et al.*, 2009). The increased scope for considering a more extensive range externalities, under a cost-benefit and externality valuation analysis approach is consistent with the tone of regional water supply assessments and the recognised need to incorporate the full gamut of environmental, social and economic factors in assessing water servicing options for the region (see *Water Act 2000,* Section 346 (3,e, i) p.269). It will also be of substantial value for evaluation and decision-making in the *South-East Queensland Water Strategy* which embraces the value of TBL accounting of major infrastructure and technological options (QWC 2009).

2. METHODOLOGY AND BACKGROUND

2.1. Overview

This report is aimed at providing water managers with a detailed reference to help incorporate the full range of costs and benefits into option and scenario assessment and decision-making for alternate options under consideration in TWCM planning. The selection of options, and focus on particular externalities, has been based on the specific planning and local context features of the MBRC. However, the approach, and much of the information provided, should be of more widespread use and potential adaptation for TBL assessment of water servicing options in other political and geographic settings.

The analytical focus here is upon externalities, or those effects beyond direct financial costs and benefits. Improved identification and information about likely external effects of alternative water options, and the magnitude of their impacts in terms of "trade-off" or economic values, is vital for assessing the full range and longer-term impacts of projects and policy, and hence the efficient allocation of resources available to society. It can also assist in avoiding unexpected costs later in the project cycle (Siebert, Young and Young, 2000).

2.2. Background

TWCM is a major directive in the South East Queensland Water Strategy (SEQWS) (QWC, 2009 p 27). Key features of TWCM include:

- water efficiency and recycling
- **the integrated management** of urban and rural water
- water sensitive urban design
- **stormwater management** – in line with natural flow patterns
- a focus on **catchment management** to protect waterway health and drinking water supply.

However, new legislation introduced to Queensland (the *Environmental Protection (Water) Policy 2009*) requires that local governments above a certain population size (or under some other conditions) formulate TWCM plans as "an environmental plan about water cycle management" (Qld Government 2009). These plans provide guidance in operation and decision-making regarding water servicing options and their associated effects at the local level, and must be in accordance with the guidelines prepared by the (then) Department of Environment and Resource Management (DERM).

A key feature of TWCM plans is the "integrated use of water" which has been assumed to refer to the integrated assessment of various environmental (and hence social and economic) impacts of potential water servicing options. The plans include the need to consider trade waste, sewage, health and safety, ecosystem impacts and cultural, spiritual and recreational values and the various trade-offs between economic and social impacts and "environmental values". Hence, the ability to assess trade-offs between water project impacts is vital and externality analysis and valuation can play a key role in providing this information across an extensive range of effects. In addition, all plans must incorporate rainwater and stormwater harvesting, wastewater harvesting and Water Sensitive Urban Design (WSUD) principles.[3]

The MBRC region borders the north of the Brisbane City Council in the coastal south-east corner of Queensland (see Figure 2). It covers 2037 sq.kms and has a population of 389,661 (MBRC, 2012). It is undergoing one of the most rapid expansions in urban development in Australia and its population is expected to grow to 533,170 persons by 2031. The political region encompasses 14 catchments and multiple water ways and supply sources and a wide diversity of residential, rural and commercial land uses.

[3] WSUD involves the integration of the water cycle and its diverse range of interconnected natural functions and processes (and ecosystem and direct services to humans), with urban planning and design. Important aspects emphasised under WSUD factors are drinking water, stormwater run-off, waterway health, sewage treatment and recycling. See http://waterbydesign.com.au/whatiswsud/ for more detail.

Figure 2: The Moreton Bay Regional Council – Location Map.

Source: (BMT WBM 2012)

Box 1 - Some Key Water Cycle and Management Features of the MBRC

The BMT WBM (2010, p.11) report summarises some key features of the overall natural and anthropogenic water systems of the Moreton Bay Regional Council (MBRC):

Future land use (i.e. 2031) in the MBRC region is expected to consist of approximately 17% urban, 27% agriculture and 56% conservation area / green space.

Stormwater runoff is drained by a number of major waterways in the MBRC region including Stanley River, Caboolture River, Pumicestone Passage, and Pine River. These waterways discharge into Moreton Bay (Bramble Bay and Deception Bay). Based on 2010 EHMP scores, water quality in Stanley catchment is B-, Caboolture estuary is D, Pumicestone Passage is D+, and Pine estuary is C-. Bramble Bay and Deception Bay received a score of D+. In regard to flooding issues, MBRC is developing a Floodplain Management Plan in parallel with the TWCM Plan, which will be a companion document to the TWCM Plan. Potable water is sourced a number of surface water storages including North Pine Dam, Lake Kurwongbah, Woodford Weir, and the Caboolture Weir, and also groundwater storages including Bribie Island borefield and Dayboro borefield. Potable water is also imported from the Sunshine Coast via the Northern Pipeline Interconnector (NPI) and also exported to Brisbane.

Wastewater is treated at eight sewage treatment plants (STPs), including Bribie Island, Caboolture, Burpengary East, Woodford, Dayboro, Redcliffe, Murrumba Downs, and Brendale STPs.

There are a number of key conservation areas in the MBRC region comprising national parks, state forests, conservation areas, reserves, wetlands and areas declared as High Ecological Value (HEV) areas as per the EPP Water.

In Figure 3, a water flow analysis showing the major movements of natural and anthropogenic intervention water (by major type) is shown for 2010 as well as some estimated predictions for 2030 (subject, of course, to planning choices). This simple accounting framework reflects the mass or material balance basis of resource assessment and provided an important platform for the design and analysis of sustainable water servicing options in the region.

The key principles outlined in the TWCM Strategy for Moreton Bay (BMT WBM 2010, 2012) closely align with those laid out in the SEQWS. Shared features include:

- minimising alterations to natural water cycles;
- maintaining sustainable limits to use;
- maximising water conservation;
- ensuring that there is an adequate diversity of water supplies available;
- maintaining a high level of water quality for the community and the environment, and,
- aiming to achieve water quality that is 'fit for purpose' (i.e. ensuring efficiency through being no better or worse than required).

There are a series of drivers behind the adoption of TWCM principles in the Moreton Bay study region. Firstly, as highlighted by the infamous 'Millennium Drought', there is a need to ensure water supply security. This will be aligned with considerations regarding the 'fit for purpose' initiative outlined above. In addition, there is a recognised need to ensure that the health of waterways is maintained through adequate environmental flows (BMT WBM 2010). Rapid population growth is another key driver. High levels of population growth are predicted within the MBRC area, especially in the identified growth areas of 'Caboolture Identified Growth Area' (CIGA), 'Morayfield and Narangba Transport Precincts', 'Elimbah East' and the 'Northern Growth Corridor' (BMT WBM 2010, p.5). Flooding, water quality, conservation of protected areas, water industry institutional arrangements and legislation are also key drivers for TWCM in the region.

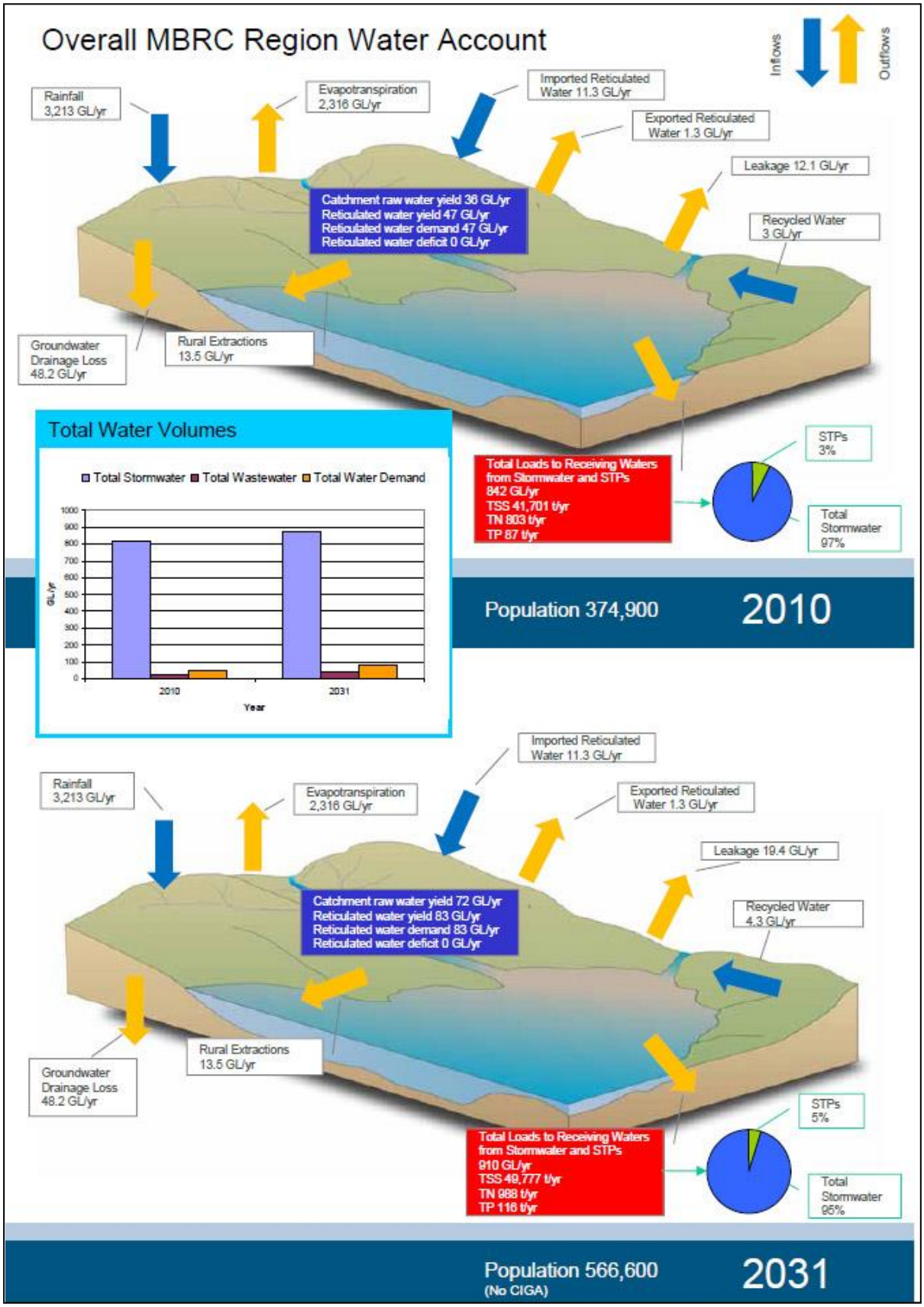


Figure 3: The Moreton Bay Regional Council – Overall Region Water Account.

Source: BMT WBM (2010)

The TWCM Strategy for the Moreton Bay Regional Council has identified a number of potential "solutions" as viable options for TWCM planning. The solutions are management options which address one or more of the issues and drivers identified in the Moreton Bay TWCM Strategy (BMT WBM 2010). They have been identified by policy-makers and then developed using a multiple criteria analysis approach with further refinement leading into phase two of the TWCM planning process. The BMT WBM (2012, p.xvi) report explains:

> *...solution sets contained within the three management scenarios for each catchment were assessed to quantify outcomes in terms of environmental, economic and social performance. Results from the management scenario assessment were then used to determine the preferred scenario for implementation in each catchment, using a multi criteria assessment (MCA) process. This MCA process takes into account environmental, social and economic factors when determining the preferred scenario.*

The complete set of options or solution sets are listed in Table 1. As noted, given the limit research scope for this study, the exploratory analysis of externalities and valuations has been restricted to S5, S6, S9 and S10 and the solution set associated with "Future development meets QDC (Queensland Development Code) alternative water supply mandate" which, in practice, essentially involves the implementation of rainwater tanks in greenfield development sites. S9 is based on retrofitting rainwater tanks and has been effectively combined with the QDC solution set covering new rainwater tanks in greenfield sites in the following analysis. A more detailed analysis would need to provide a better separation of the relevant external effects for these options.

These solution sets were then utilised as the basis for developing and investigating three "management scenarios" for each catchment. The scenarios were built in an incremental fashion with higher intensity scenarios including the solution sets of the lower level scenarios. This facilitated the measurement of the effect of applying additional options, and the cost-effectiveness of doing so.

The management scenarios investigated for each catchment were divided into:

(a) **Low Intensity Scenario**: These management scenarios included those solutions deemed to reflect "business as usual", that is compliance with pollutant load reduction targets for new development under the State Planning Policy for Healthy Waters (SPP HW), and water saving targets required by the Queensland Development Code (QDC).
(b) **Medium Intensity Scenario:** These management scenarios added those solutions identified in each catchment as 'easy to do' and most preferred (considered most cost effective opportunities, low risks) as a result of stakeholder feasibility assessment workshops.
(c) **High Intensity Scenario:** These management scenarios will then add those solutions that may be considered to stretch the limits in terms of the expected costs and risks identified during the solution feasibility workshops (BMT WBM, 2012).

The solution sets considered for each scenario are shown in Table 2 below. As noted, the more intensive scenarios include in the solutions in the lower intensity scenarios. Solution feasibility assessment expert workshops were organised to identify solutions that were appropriate for each catchment and hence worthy of further detailed analysis. These solutions were then subject to cost-effectiveness analysis (CEA) relating to certain environmental, economic and social performance criteria. The results from this assessment were fed into a multi-criteria assessment (MCA) process where selected stakeholders used the information, and preference, ranking and scoring procedures to score the solution impacts in terms of major evaluation criteria. Score were based on assessment for each catchment. The evaluation criteria (e.g. "changes in hydrology" or "public acceptability") were weighted according to their perceived importance, and then used to weight the solution scores. These results were then combined to generate overall scores for each solution and the subsequent identification of the preferred scenario(s) for each catchment.

Table 1: Moreton Bay Regional Council MCA Options Analysis.

Solution Implementation Key: Council Policy / Council Infrastructure / Unitywater	Catchment											
	Stanley	Pumicestone	Bribie	Caboolture	Caboolture CIGA	Burpengary	Upper Pine	Lower Pine	Sideling	Hays	Redcliffe	Brisbane Coastal
S5: Recycled Water Supplied to Urban Users				X	X	X		X		X	X	
S6: Recycled Water Supplied to Agricultural Users	X			X	X							
S7: Sewer Mining - Small Community Based Plants to Treat and Reuse Sewage	X			X	X	X	X	X		X	X	
S8: Indirect Potable Reuse of Purified Recycled Water (PRW)				X	X			X				
S9: Rainwater Tanks Retrofitted for Non-Potable Uses		X	X	X	X	X		X		X	X	
S10: Stormwater Harvesting for Non-Potable Uses	X		X	X	X	X		X		X	X	X
S14: Pressure Reduction on Trunk Water Supply Infrastructure	X											
S16: Education & /or Capacity Building and Investment in Incentive Schemes	X	X	X	X	X	X	X	X	X	X	X	X
S23: Upgrade STP Infrastructure	X			X	X		X	X		X		
S25: Diversion of Sewage to STPs with Capacity				X	X			X				
S26: Smart Sewers (Reduced Infiltration/Inflows)	X		X	X	X	X	X	X		X	X	
S27: Prevention of Illegal Stormwater Inflow Connections to Sewer	X			X	X	X	X			X	X	
S29: Waterway Rehabilitation - Riparian Zones (3/4 Order Streams)	X	X		X	X	X	X	X	X	X	X	X
S30: Increased Implementation of Erosion & Sediment Control on Development Sites	X	X	X	X	X	X	X	X	X	X	X	X
S31: Existing Water Sensitive Urban Design (WSUD) Retrofit		X	X	X	X	X	X	X	X	X	X	X
S32: Future Development WSUD Measures Achieve No Worsening	X	X	X	X	X	X	X	X	X	X	X	X
S33: Rural Best Management Practices (e.g. Limiting Erosion etc)	X	X		X	X	X	X	X	X			
S35: Cap at current Population Without Any Other Solutions Implemented	X	X				X	X					

More intensive scenarios typically involved higher capital costs and more challenging technological and social options but have different potential cost-effectiveness in terms of combining economic, environmental and social performance outcomes and targets. The MCA process helps provide a balanced assessment of variable environmental and social performance of each solution and scenario against the economic costs involved.

2.3. Methodology

In order to meet its primary aim of generating supporting information and methods for the TBL assessment of the solution sets or options being considered for a TWCM approach in the MBRC, this report provides three main sets of results:

(1) The detailed identification of external effects likely to be associated with alternate water options for the Moreton Bay Regional Council (Chapter 3)

Firstly, the report builds upon the earlier background research in Daniels *et al* (2012) to provide an updated and more extensive review and compilation of the external costs and benefits of the ***three general options*** that are considered central in the TWCM planning process in the MBRC – *wastewater recycling to urban and industry uses, stormwater harvesting and rainwater tanks (in greenfield sites).* The sources of information for this review include technical descriptions of each water servicing option, more specific externality studies (especially those related to water), and relevant background information on the MBRC case study context.

Table 2: Solutions and Management Scenarios Investigated in the MBRC.

Management Scenarios	Catchment											
	Stanley	Pumicestone	Bribie	Caboolture	CIGA	Burpengary	Upper Pine	Lower Pine	Sideling	Hays	Redcliffe	Brisbane Coastal
Scenario 1: Low Intensity												
Future development meets 80/60/45% load reduction for TSS/TP/TN	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
Future development meets QDC alternative water supply mandate	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
Scenario 2: Medium Intensity												
Increased implementation / enforcement of E&SC management practices	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
Waterway riparian revegetation of 3rd & 4th order streams	✓	✓		✓	✓	✓	✓	✓	✓	✓		
Rural BMP for grazing land - revegetation of 1st & 2nd order streams	✓	✓		✓		✓	✓	✓	✓			
Rural BMP for horticultural land - implementation of filter/buffer strips	✓	✓		✓			✓	✓	✓			
Education & /or capacity building and investment in incentive schemes	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Prevention of illegal stormwater inflow connections to sewer	✓			✓	✓	✓	✓			✓	✓	
Recycled water supplied to land / agricultural users	✓			✓								
Recycled water supplied to urban users					✓			✓		✓		
Scenario 3: High Intensity												
WSUD retrofit to existing urban areas		✓	✓	✓		✓		✓		✓	✓	✓
Future greenfield development WSUD measures achieve 'no worsening'	✓	✓		✓	✓	✓	✓	✓		✓		
Recycled water supplied to urban users				✓								
Large-scale stormwater harvesting for non-potable use (greenfield sites)	✓				✓	✓		✓		✓	✓	
Indirect potable reuse of Purified Recycled Water (PRW)					✓			✓				
Rainwater tanks retrofitted to existing urban areas for non-potable use		✓	✓								✓	✓

The main result of this work is the production of three large tables listing the major externalities associated with water recycling, stormwater harvesting and rainwater tanks (for example, see Table 3). Where possible, the research focuses and highlights those externalities most relevant to the MBRC. This process has been guided by knowledge of the local government area's technical, urban and economic structure, geographic, and socio-demographic context. While economic and environmental impacts are often the exclusive focus of impact research related to natural resources, the externality analysis information compiled here has also explicitly targeted more intractable, *social* externalities where possible.

The externality tables identify individual external effects and classify them according to a typology linked to total economic value (TEV) type(s) affected and also by their relevance to the life cycle stages of the intervention under study (e.g. GHG emissions in the construction phase of rainwater tanks). A concise description of the external effect is provided and it is noted whether the effect: (1) tends to be positive or negative impacts (or both); and (2) occurs upstream, downstream or in the vicinity of the supply infrastructure. Coded reference links are also provided to key existing empirical studies or works examining and describing the external effect.

(2) The compilation of an extensive range of economic valuation estimates for the relevant set of identified water-related externalities (Chapter 4)

The second major set of results is a detailed compilation of existing monetary valuation estimates for each of the external effects from the identification process in (1) above. These valuations were gleaned from a diverse range of existing environmental economic research. Details of the relevant economic valuation techniques (and their links to TEV types and the externality effects) have been provided in the previous two reports by the authors (Daniels *et al.,* 2012; Daniels, Porter, and Bodsworth, 2012). The original estimates have been converted to 2010 Australian dollar equivalents in order to facilitate ready comparison. They are presented for use in a general "transfer benefits" sense where the estimates can be considered as indicative and subsequently utilised with qualification or with modification based on known local conditions. Of course, they can be rejected or simply used as comparative measures when primary research is possible or required given unique or very different contextual settings.

(3) An example application of the externality economic valuations based on total GHG emissions for the three management scenarios across the MBRC catchments (Chapter 4)

Together, the description of externalities linked to specific water options and the detailed set of monetary valuation estimates provide a useful resource for researchers and planners – one which can feed information on the extent of "trade-offs" involved, into most decision-making frameworks for future water supply planning in the Moreton Bay Regional Council. This includes decision-making tools such as multiple criteria assessment and cost-benefit analysis (see Daniels, Porter and Bodsworth, 2012).

Externality valuations attempt to identify the trade-off values associated with the TEV or services (direct economic and more indirect ecosystem services) of natural resources. Changes in these TEV services due to human interventions can often be estimated using various valuation techniques.

The total economic value of a natural resource is a composite of the positive values or benefits of a natural resource from the complete range of functions and services it provides to human society. The purpose of the TEV scheme is to systematically identify, compile, and potentially measure all of the economic and socio-cultural benefits of natural resources (including long term services, and from local to global community effects). It covers the source, sink, life support and amenity values functions of nature. A more detailed description of TEV is provided in the accompanying report (Daniels, Porter, Bodsworth and Coleman, 2012).

Externalities can be classified in many different ways. The approach taken in this report has been influenced by the original research focus on water options for the Logan-Albert catchment in SEQ. Given the emphasis prescribed for the UWSRA project, the analysis of externalities has concentrated on GHG emissions and related energy use, and nutrient and sediment impacts. However, other significant environmental flows and state changes associated with the range of options can include other water quality issues, and ecosystem and biodiversity changes. This more complete range of effects has been included in the analysis.

While such measures represent biophysical pressure or state changes, it is also useful to consider the socioeconomic effects of such changes. For example, GHG emissions can have a broad range of actual costs and benefits upon society, ranging from changes in direct economic output, health, and loss, through to rapid shifts in habitat or biomes. Hence, a range of additional externality types – based on actual socioeconomic costs and benefits of option impacts – have been included in the externality "checklist". These include costs and benefits on production, recreation, amenity, health, and non-uses (such as existence or vicarious welfare effects and options for use in the future). Many of these impacts are also inter-related. For example, health impacts will affect economic production.

The externality categories adopted here are based on the TEV approach and have been selected in view of their identified relevance and application throughout the existing research on water-related externalities (for example, see Young, 2000). The classification scheme is presented in Table 3.

Table 3: The classification of externality types.

Externality Type	Abbreviation	Description
Pressure or State Change Indicators		
Greenhouse Gases	GHG	The GHG emissions associated with the water option.
Energy	En	The energy consumed by the water option (ideally throughout its life cycle).
Water Quality	WQ	The impacts, positive or negative, which the option has upon water quality. This could relate either to the actual water supply or demand change from the option or its impact upon the water quality of surrounding waterways.
Nutrients	N	The nutrient loads and associated effects resulting from the water service option.
Ecosystem	E	Impacts which affect the ecosystem. This refers to the ecosystem as a whole, including the interactions between various species, for example, a wetland or a waterway.
Biodiversity	B	Impacts which affect the biological populations of the area in question. These externalities refer to a specified population or community within an ecosystem, for example, waterbirds or the lungfish, or even waterside native vegetation.
Socioeconomic Costs and Benefits		
Production	P	The impacts that the option has upon any commercial industries, specifically in terms of indirect third party external impacts e.g. desalination effects reducing fish populations and associated catches.
Recreation	R	Impacts which affect people's recreational activities. These can be positive (e.g. provision of additional areas for swimming) or negative (e.g. decreased access to walking tracks).
Amenity	A	The impacts upon the amenity of the region, e.g. desalination plants may detract from the amenity values of the coastal ecosystems.
Health	H	Impacts which affect human health.
Non-Use	NU	Non-use values are those which make up the total economic value (TEV) of a resource. TEV consists of both use and non-use value (see Figure 1).
Other	O	Other significant impacts which do not fit the existing categories.

There are seven steps proposed in the simple externality analysis (SEXTAN) method recommended to expand the extended cost-effectiveness analysis work completed for the project (main Hall reference needed here) to more comprehensive TBL accounting of water servicing options or solution sets in the MBRC. The SEXTAN methodology is explained in detail in the project report by Daniels, Porter and Bodsworth (2012).

The first step in the SEXTAN method would equate to the formulation and specification of the TWCM strategy "solution sets" (e.g. S5, S6). The complete method includes the following seven steps:

1. Scenario composition based on the contribution of component water supply options.
2. Given the options comprising each scenario, identification of the major externalities associated with these options.
3. For each option in the scenario, the biophysical or socioeconomic (non-monetary) quantification of each externality generated per unit output of required water quality from that option.
4. The economic valuation of relevant *per unit* biophysical or indicator externality impacts (typically biophysical) for *each* option.
5. Calculation of *each* externality type's cost/benefit *per unit* water service change.
6. Calculation of the total dollar value cost or benefit of each externality effect from the *total* planned change in water service.
7. Include the externality valuation results into decision-making processes; either separately for each externality impact or aggregated in various ways for the alternatives being assessed.

The main externality identification tables provide major guides and information feeds for Step 2 and the economic valuation estimates in Chapter 4 of this report provide the major data source for Step 4. Step 1 is completed in the initial strategic planning process and Steps 3-5 require scientific research and technical understanding to identify biophysical and other quantitative dose-response relations associated with the water servicing option, or "solution set" under study.

3. EXTERNALITY IDENTIFICATION FOR THE STUDY SOLUTION SETS

This chapter analyses the externalities associated with the three major sets of options selected from a larger number of "solution sets" that make up the management scenarios investigated for TWCM in the Moreton Bay Regional Council region. The main purpose is to identify, compile and provide basic background information on the nature of the externalities of these TWCM solutions. Additional information describing the solution sets investigated for the MBRC TWCM Plan can be found in BMT WBM (2012).

As outlined previously, the project team leaders directed the focus of more intensive analysis to stormwater harvesting (Solution 10 or "S10"), wastewater recycled to urban and industrial uses (S5 and S6), and "rainwater tanks" which is a combination of S10 ("rainwater tanks retrofitted to existing urban areas for non-potable use") and the solution set associated with "Future development meets QDC alternative water supply mandate" which, under the procedure adopted in the MBRC TWCM Plan (BMT WBM, 2012), essentially involves the implementation of rainwater tanks in greenfield development sites. The MBRC catchments where these solutions were investigated are shown in Table 4.

The primary results are presented in the main externality tables for Table 7 (rainwater tanks), Table 9 (stormwater harvesting) and Table 11 (wastewater recycling). A summary of major external effects relevant to the MBRC is provided in Chapter 4.

Table 4: Solution Sets investigated in the report – their relevance to each MBRC Catchment.

Solution Set / Management Scenario	Stanley	Pumicestone	Bribie	Caboolture	CIGA	Burpemgary	Upper Pine	Lower Pine	Sideling	Hayes	Redcliffe	Brisbane Coastal
"RAINWATER TANKS" Future development meets QDC alternative water supply mandate (in Scenario 1: Low Intensity)	□	□	□	□	□	□	□	□		□	□	□
Rainwater tanks retrofitted to existing urban areas for non-potable use		□	□								□	□
"WASTWATER RECYCLING" Recycled water supplied to land / agricultural users (in Scenario 2: Medium intensity)	□			□								
Recycled water supplied to land / agricultural users (in Scenario 2: Medium intensity)						□		□		□		
"STORMWATER HARVESTING" Large-scale stormwater harvesting for non-potable use (greenfield sites) (In Scenario 3: High intensity)	□					□		□		□	□	

Some pertinent features for the identification of externalities related to the three main supply options considered in the solution sets in this study are outlined in Table 5 below.

Table 5: Important Features of the Major Supply Options Relevant for Externality Analysis.

	Rainwater Tanks	Stormwater Harvesting	Wastewater Recycling
Relevant process dimensions	Roof → tank → user Note that rainwater treatment is not included. Tank configuration as per the QDC requirements.	Post WSUD → storage/ treatment reticulation	Post STP → treatment reticulation
End-uses in the MBRC study	Garden, toilet, laundry	Garden, toilet	Garden, toilet
Water savings per installation	Hard to predict (modelling challenges). Also, much uncertainty whether or not people to continue to use the tanks over the long term.	Hard to predict (lack of empirical data)	Hard to predict (lack of empirical data)
Scale at which these could be implemented (in practice)	Potentially large, because not constrained by capital expenditure budgets.	Probably smallest of the 3	Reasonable but capital expenditure is a real limitation.
Climate resilience	Medium	Medium	High
Key diversion	Stormwater	Stormwater	Wastewater
Key material and energy inflows – non-water (more extensive life cycle and supply chain analysis would be valuable here)	Power use	Power use; chemicals use	Power use; chemicals use
Key outflows – non-water	Tank sludges (although virtually no data on how this will manifest itself over large numbers of installations); Disposal of tanks at end of life; GHG emissions from pumps	Treatment sludges (possibly, although depends on technology choice); Fugitive N2O (depends on treatment approach, and there are no data available)	Treatment sludges (possibly, although depends on technology choice); Fugitive N2O (depends on treatment approach, and there are no data available)
Construction aspects	Impacts associated with manufacture will vary greatly depending on materials type	Presumably will be as per WW recycling	Limited available data suggest that the distribution networks could be the most materials intensive part of the system/ Therefore the impacts will depend on the choice of piping materials.
Infrastructure disposal	Potentially a high degree of recycling could occur but may be constrained by the predominance of plastic tanks, and questionable whether people will have sufficient motivation.	?	?

In terms of energy use, all three main options considered will involve higher energy use per kL than conventional dam-based mains supplies but will be lower than sea water desalination. For RW tanks, there will be some houses with a higher GHG intensity than for desalination but, on average, the available data suggest that the average household RW tank installation will have a lower energy/GHG footprint than desalination sources (Lane *et al.,* 2010).

It is important to note, at the outset, that all three major options investigated here (rainwater tanks, wastewater recycling and stormwater harvesting) act to reduce mains water demands. Hence, the external effects linked to this reduction in mains water demand will be common to all – subject, of course, to the extent to which the solutions lead to mains water savings. The deferral of the construction and operation of large-scale water supply infrastructure involves significant benefits to the community, both economically and socially (Knights and Wong, 2008; Kuczera, 2008). Triple bottom line (TBL) benefits occur because alternative large scale infrastructure are often characterised by adverse and unequal impacts across the community - for example, social dislocation and loss of agricultural land from the establishment of new dams, and GHG emission and energy security problems associated with desalination.

3.1. Rainwater Tanks

This section provides a summary of relevant technical, process or engineering aspects of rainwater tanks for the purpose of identifying relevant externalities that might be associated with this solution set. The emphasis is upon externality impacts and not the private or financial costs and benefits that are directly involved in intentional, fully-informed market transactions. As noted, this section covers both rainwater tank implemented in greenfield site as well as retrofitting of urban areas.

There was a mandate introduced, in January 2007, in SEQ, which required new detached homes to provide at least 70 kL of water per year of their own. The most common means of achieving the 70 kL provision is for tanks to be connected to toilets and laundry as well as for outdoor use.

Under the new Queensland Development Code MP 4.2 (QDC MP 4.2), a rainwater tank must:

- have a minimum storage capacity of at least 5,000 litres for detached class 1 buildings houses) or 3,000 litres for a non-detached class 1 building (townhouses, terraces);
- have a roof catchment area of at least one half of the total roof area or 100 m2, whichever is the lesser;
- supply water to at least one external tap and internally to all toilet cisterns and washing machine cold water taps;
- ensure a continuous supply of water to all internal fittings through either an automatic switching device or trickle top-up system;
- incorporate appropriate back-flow prevention devices to prevent tank water from entering the reticulated water supply network;
- incorporate acceptable screens or methods of preventing mosquitoes and vermin entering the tank.

This mandate has promoted an increase in tank installations and, as of 2009, approximately 40% of houses in the SEQ region have one or more rainwater tanks (Gardiner, 2009). The TWCM Strategy assumes a rainwater tank uptake of 25% in the MBRC region (BMT WBM, 2012).

Rainwater tanks are also increasingly being used in industrial or commercial complexes due to the large roof areas available. Water collected on these buildings is used to off-set mains water consumption for specific uses regarding the business or for general cleaning and irrigation. Local government planning requirements usually determine whether a development approval is required for the installation of rainwater tanks associated with detached houses.

Rainwater tanks are often marketed as a water supply option that saves both the individual and society money. However, this is subject to some debate within the literature. The true nature of avoided cost for water tanks remains unclear but what is apparent is that the economic benefits and costs derived from rainwater tanks is highly variable. Some studies have claimed that existing studies of the benefits and costs of rainwater tanks have downplayed the significance of the benefits that accrue at the regional scale with the widespread uptake of rainwater tanks (Coombes, 2007).

Rainwater tanks can have community benefits through the deferral of large scale water infrastructure, reduced peak stormwater flows, and sediment transport (Coombes and Kuczera, 2003, p.1; Blue Scope Steel; Mitchell and Rahman, 2007). These benefits are closely linked to other externality impact categories such as ecosystems, nutrients, production, and amenity. Through the capture of stormwater, nutrient loads to oceans and waterways may be significantly reduced. For example, there are estimates suggesting that phosphorus loads may be reduced by 68% (Hallmann, Grant and Alsop, 2003). In addition, the TSS levels of stormwater runoff were predicted to be reduced by 90% when rainwater tanks are utilised (Khastagir and Jayasuriya, 2010, p.329).

Rainwater tank use can also reduce mains water consumption and thus presenting potential financial benefits to the individual (Coombes and Kuczera, 2003, p.1; Eroksuz and Rahman, 2010). These savings can be significant, with estimated that a tank installed in a single dwelling can reduce mains

consumption by 30–39% and for a townhouse 27–32% (Coombes *et al.*, 2002, p.121). It has been found that the larger tanks accumulate higher mains water savings than smaller tanks, with estimates that a 70 L tank can meet a households water needs (for toilet flushing, laundry, hot water and outdoor irrigation) for 50% of the year (Eroksuz and Rahman, 2010).

For SEQ, where installation of internally plumbed rainwater tanks for toilet, clothes washing and garden uses is mandatory in all new houses, the long-term expected rainwater tank yield has been estimated at 37 kL/household per year (Coultas *et al.,* 2012). Assuming that most of this use represents actual savings to total household consumption, the result may be the substantial reduction or deferral in infrastructure requirements – including new dams, pipelines, and stormwater storage (Coombes and Kuczera, 2003; Blue Scope Steel; Mitchell and Rahman, 2007; Knights and Wong, 2008). The extent of these infrastructure economies will vary greatly, depending on the local conditions (Marsden Jacob Associates, 2007b). However, research suggests that, conditional upon roof area size, the cost of tank water is higher than that charged by utilities – especially in Brisbane where the long run marginal cost of rainwater tanks to the community is estimated at over $2 per kL (Marsden Jacobs Associates, 2007b). The Marsden Jacobs (2007b, p.ES.x) report also notes that the "primary financial benefit of rainwater tanks to the community (in contrast to the individual property owner) is the potential reduction in the cost of water and stormwater infrastructure".

Increased use of rainwater tanks can also result in less frequent overloading of sewer systems and overflows that lead to health and economic benefits for the community (Vaes and Berlamont, 1999). When storage space is available in tanks there is a decrease in overall overflow volumes and in the peak discharge volumes (see Figure 3.20, Vaes and Berlamont, 1999). According to Coombes *et al.,* (2002, p.121) "for allotments with single dwellings between 50 to 70% of the tank volume can be counted towards the allotment's OSD [on-site stormwater detention] volume. For a townhouse development this percentage varied between 36% and 53%". Thus, rainwater tanks may slow further expansion demands for sewerage systems and provide a comparatively cheap abatement tool for addressing overflow emissions (Vaes and Berlamont, 1999; Coombes, 2007).

The extent of beneficial spill-over impacts of rainwater tanks upon stormwater systems is contested. To some extent, this is due to the dependencies these systems face with seasonal variation and the storage space available in the tanks (Vaes and Berlamont, 1999). In addition, some studies focus on peak discharge rates at the allotment scale and others target the regional scale. Those that study stormwater impacts at an allotment scale may be at risk of downplaying regional stormwater benefits that are considered cumulative in nature (Coombes *et al.*, 2002).

While the evidence for financial cost savings of rainwater tank water supply is not positive (see Stewart, 2011), Marsden Jacob Associates (2007a, p.ES.2) note some of some of the external benefits of this option, including:

- mitigation of the costs and impacts of water restrictions on their lifestyle, amenity and property values (for example, avoiding the death of non-drought resistant plants, losses in property value or reductions in the availability of home grown fruit and vegetables);
- improvement in the taste of water in areas of poor water quality;
- help avoid the environmental [and other TBL] impacts of constructing new water sources; and
- positive community-mindedness effects (i.e. easing the burden on the public water supply).

Householders and communities receive benefits relating to recreation and amenity. Gardening is a popular pastime for many householders and the onset of water use restrictions had significant adverse implications for this form of recreation. Water restrictions have also impacted on the amenity of neighbourhoods, with gardens dying off due to drought conditions. Rainwater tanks are able to mitigate the effects that water restrictions have on lifestyle, amenity and property values through enabling garden watering throughout drought periods (Tam *et al.*, 2009).

Rainwater tanks can also assist in creating water and food and water security within our communities (Coombes, 2007; Coombes and Barry, 2008). Decentralised sources help diversify the water supply

system and create inbuilt resilience, thus assisting in lessening the water crisis on an individual and societal level (Tam *et al*., 2009; Helmreich and Horn, 2009). Furthermore, decentralised water supplies create:

- safety nets against terrorist attacks (Mitchell and Rahman, 2007);
- enable people to continue with small scale productive activities (e.g. brewing, food production, household construction) (Helmreich and Horn, 2009; Kahinda *et al*., 2007).

Furthermore, communities can benefit in less obvious ways relating to non-use values. The adoption of rainwater tanks within communities can promote better stewardship of water at the household level (Marsden Jacob Associates, 2007a; 2007b). It can also foster a sense of community-mindedness, acting as a form of environmental education promoting awareness of sustainable water use (Furumai, 2008, p.340; Marsden Jacob Associates, 2007a or b, p.4).

Other external, or at least indirect, financial and other costs associated with operating and maintaining tanks include:

- energy costs for pumping;
- time and effort spent for regular checking and cleaning of gutters, roof catchments and tank screens, including removing overhead branches where required;
- potentially installing gutter screens or guards;
- checking the tank for sludge every two to three years and having the tank cleaned if there is a thick layer of sludge at the bottom;
- possible chlorine disinfection; and
- maintenance of the water pump as required.

The cost of rainwater tanks includes the tank, installation and pump, as well as land area foregone. Rainwater tank storages can take up significant proportions of individual block and, in cases where garden space is small it may impinge on the aesthetics and useable space. New and innovative tank designs are serving to mitigate this issue.

There are potential health risks associated with the storage of large volumes of water on individual blocks. While largely overcome in the urban setting given current regulations, rainwater tanks may pose a drowning risk (Byard, 2008). This danger may be minimised through the removal of all ladders, vegetation, and trellises which provide points of access. In addition, extra precautions of secure child-proof access points can be installed, particularly on in-ground tanks.

Another important potential health hazard is that rainwater tanks can provide breeding sites for disease vectors such as mosquitoes (Ritchie *et al*., 2002, p.13). Mosquitoes are vectors for serious diseases such as dengue, Ross River virus and malaria. However, breeding can be prevented by proper maintenance of rainwater tanks to ensure that they have adequate screens and are sufficiently sealed, and with periodic treatment or draining.

In addition, a recent study has highlighted financial and inconvenience costs associated with rainwater tank first flush system blockages as another significant factor affecting tank owners Gardner and Vieritz, 2010). Blockages can result from the manufacture of capillary valves (essential components of the tank) and may leave tank owners inconvenienced or forced to pay for replacement or repair.

Externalities arise in regard to the use and distribution of tank water; mostly concern health effects and energy consumption. These concerns in the research literature are not, however, necessarily reflected in public perceptions. In a 2000 study in Newcastle, NSW, 95% of participants were happy to use the rain water collected for toilet flushing, hot water systems, clothes washing and cooking; whilst 70% considered rainwater tank water to be a possible source of drinking water (Coombes, Argue and Kuczera, 2000). The suitability of rainwater for drinking water is controversial, as the water quality is not regulated in the same way as mains water supply. Water quality collected in rainwater tanks is directly impacted by the characteristics of the roof catchments and run-off contamination (Evans *et al*.,

2006). Contamination can be a result of atmospheric deposition; from chemicals and micro-organisms; faeces from birds and small mammals (e.g. possums); and decaying organic debris (Evans *et al*., 2006; Helmreich and Horn ,2009). The potential for individual health issues to become a public health issue are there, considering one in five rainwater tank owners (in newly constructed homes) have reported frequent use of the rainwater for drinking and cooking (Gardiner, 2009). The health impacts of rainwater tanks primarily arise due to either; contamination of the rainwater or the provision of insect vector breeding grounds (Kahinda *et al*., 2007; Goodall, 2000).

The specific pathogens identified in tanks are diverse. Some species found in rainwater tanks include; *Salmonella, Shigella, Vibro, Clostridium, Legionella,* Campylobacter, Cryptosporidium, and Giardia spp. (Evans *et al*., 2006, p.37). These pathogens as well as their transmission route and incidence are described in the table below. Whilst these pathogens may be found in tanks, it should be noted that there are relatively few reported cases of disease outbreaks from rainwater use worldwide (Lye, 2009). From 1978 – 2006, there were only six reported cases, however, in a short period since 2006, three new outbreaks have occurred. There may be many other cases of other outbreaks going unreported (Lye, 2009 p.5432). A list of pathogens commonly found in rainwater supplies in developed countries and the potential risk is described in Table 4.

Specific atmospheric pollutants found in rainwater tanks are dependent upon numerous factors, including quality of the atmosphere of the regions (e.g. industrial versus residential) (Helmreich and Horn 2009, p.121). The types of atmospheric pollutants which may be found in rainwater tanks include; microorganisms, heavy metals, and organic substances (Helmreich and Horn 2009, p.121). Urban and rural rainfall profiles differ, with urban areas being characterised by contaminants, such as heavy metals and organic air pollutants originating from heavy traffic and industry, whilst rural water is comparatively clean except for in some instances dissolved gases (Helmreich and Horn 2009, p.121).

Table 6: A selection of pathogens common to rainwater supplies in developed countries.

Pathogen	Infection	Transmission	Case Fatality Rate per 100,000 Cases
Campylobacter spp.	Gastroenteritis	Oral	5
Escherichia coli O157:H7	Gastroenteritis	Oral	8.3
Legionella	Legionnaires	Inhalation	10,000
Pneumophila	Pontiac fever	Inhalation	Zero
Mycobacterium avium	Respiratory	Inhalation	Only in immuno-compromised
Complex	Gastroenteritis	Oral	
Salmonella spp.	Gastroenteritis	Oral	41
Cryptosporidium spp.	Gastroenteritis	Oral	22
Giardia spp.	Gastroenteritis	Oral	1

Source: Lye (2009)

In addition to airborne contaminants, the catchment surfaces themselves can be a source of heavy metals and organic substances (Helmreich and Horn, 2009). The significance of this impact depends on the type of roofing materials used. For instance, tile slates and aluminium sheeting being relatively 'safe', whilst zinc and copper roofs (high heavy metal concentrations), bamboo roofs and roofs utilising metallic paint or coatings can be sources of health hazards (Helmreich and Horn, 2009; Lye, 2009).

Long-term exposure to the some of the substances that may be present in some rainwater tank water may lead to biological disorders (Lye, 2009). The health risks are particularly significant when chemical contaminants such as pesticides, herbicides, biocides, organhalogens, and petroleum hydrocarcons are present (Lye, 2009). Whilst, there is still little in the way of literature dealing specifically with these health concerns (Lye, 2009). A recent Australian study found that rainwater

tank water quality in Australian cities is likely to meet all given Australian Drinking Water Guidelines with regards to chemicals in instances where lead flashing on the roof is exposed and there is no first-flush system thus potentially leading to high lead levels in tank water (Gardner and Vieritz, 2010).

Appendix A summarises the results of recent relevant studies dealing with the health risks associated with rainwater tank water use.

In terms of addressing the health concerns surrounding rainwater tank use, there are a series of management options which can be used to lower health risks (Sazakli *et al.*, 2007). Primarily, the maintenance of tanks can significantly reduce health risks. Some maintenance activities include, first flush systems, disinfection processes occurring regularly, mosquito screens and the regular cleaning of the tank catchment area (Sazakli *et al.*, 2007, p.2046). In general, rainwater is broadly acceptable to supply low quality domestic uses as it has had a long history for doing so and in the past was considered entirely appropriate as a drinking water source. Furthermore, there have been relatively few published cases of illness (Villareal and Dixon, 2005).

Due to the presence of these pathogens and other contaminants, some suggest, that harvested rainwater is unsuitable for drinking without treatment and suggest disinfection or other measures to improve microbiological quality (Helmreich and Horn, 2009; Kahinda *et al.*, 2007). Furthermore, studies indicate that certain rainwater systems have been so badly contaminated that they do not even reach the standards required for non-potable contact (Lye, 2009). Some studies, however, have found no elevated risk of gastro-intestinal illness resulting from the consumption of rainwater, even suggesting that rainwater generally meets international guidelines for drinking water (Evans *et al.*, 2006; Kahinda *et al.*, 2007).

Other studies show rainwater tank water to exhibit little instances of chemical contamination (Lye, 2009). This variation in scientific opinion leads to the conclusion that there is a lack of clear scientific consensus on this health risk (Evans *et al.*, 2006). Importance influences upon contamination will include catchment characteristics, proximity to pollution sources, weather and the regional topography (Kahinda *et al.*, 2007).

In addition to the social externalities associated with the use of rainwater for drinking purposes, the **distribution** of tank water for other uses (including irrigation and indoor uses such as flushing toilets) can incur significant environmental externalities.

Despite their recent portrayal as a 'green' water supply option, they are relatively energy intensive (Gardner and Vieritz, 2010). Although their data do not relate to directly the SEQ context, existing studies provide interesting information on the energy use associated with rainwater tanks. The average energy intensity of a rainwater tank, utilising a commonly used pump and rain switch system, has been measured at 1.5 kWh/kL – compared with mains supply which at around 1 kWh/kL (Retamal 2009, p.61). Another study suggests that the difference is less – with the GHG contributions from rainwater tanks 18% higher than that of reticulated water supply (Hallmann, Grant and Alsop, 2003). However, rainwater tanks have been measured to have significantly lower energy use than both wastewater recycling (at 2.8-3.8 kWh/kL) and desalination at 5.4 kWh/kL (Cammerman 2009, p. 22). The energy intensity of water tanks also varies greatly depending on the pump type and size, end-uses and the location and layout of the tank system.

Predicting rainwater tank pumping energy use is complex as it is affected by a substantial suite of variables. Empirical data demonstrates that energy use various greatly across installations (Lane *et al.,* 2010). The current norm is the installation of systems that are relatively energy-inefficient (using much more power than is necessary with best available technologies) (Tjandraatmadja *et.al.*, 2010). Given that RW tanks would be installed progressively over time, there is potential for average energy use to fall as the industry responds to recent research findings that they are selling inefficient products.

Unfortunately, there is little information available on rainwater tank disposal. Presumably, the impacts would vary according to the tank construction materials and method of disposal. Recyclability of the component parts would be another important factor for consideration.

The full range of externalities identified for rainwater tanks, with brief descriptions, are presented in the table below. A more specific list of externalities relevant in the SEQ MBRC context are provided in Chapter 4 of this report. The effects have been allocated in accordance with the life-cycle and operational phases in which they are most likely to occur. A general category is also included for effects that are not neatly classified within these phases. The externalities are also identified in terms of more general externality "types" (e.g. GHG emissions, recreation (R), and so forth) as described in the methodology section. For each specific externality, symbols indicate the typical nature of the impact in terms of whether they tend to be a positive (+) or negative externality (-); whether impacts tend to occur predominantly downstream (↓), upstream (↑), or within the immediate surrounds of the supply infrastructure (◙).

Note that most of the biophysical and quantitative socioeconomic data listed in the externality tables for each option (Tables 7, 9 and 11) is not derived from the SEQ or MBRC study context. Hence, this information must be assessed in terms of the need for adjustment and more intensive primary research in the case study areas. However, values are indicative and can, arguably, provide a comparative basis and initial estimate for ongoing research.

Table 7: Rainwater Tank Externalities.

RAINWATER TANKS	
LIFE CYCLE OR OPERATIONAL PHASE	**EXTERNALITY TYPE, DESCRIPTION (showing if positive or negative effect, main location and reference source number)** (See Appendix B for reference source code details) (See inset table to left for externality type codes)
General **Externality Type Codes =>** **GHG** Greenhouse gas emissions **En** Energy **WQ** Water Quality **N** Nutrients **P** Production values **R** Recreation values **A** Amenity values **H** Health values **E** Ecosystem values **B** Biodiversity values **NU** Non-use values **O** Other	**GHG:** GHG contributions are 18% higher than that of reticulated water supply (600L tank) (-) 49 *(= reference number – see Appendix B for details)* **En:** Potentially high cumulative energy demand (67% higher than reticulated water for a 600L tank) (-) 49 **En:** Potentially high, and extremely variable, energy intensity of water supply for the most common pump and rain switch system is approximately 1.5 kWh/kL compared to the energy intensity of mains water supply of less than 1 kWh/kL. (-) 68 **N**: Reduction in nutrients in the system, with greatest impacts when water drains to environmentally sensitive areas (+, ↓) 52, 17 **P**: Possible extension of the lifetime of existing large-scale water infrastructure by reducing peak loads and reduction in the cost of water and stormwater infrastructure (+, ↓) 22, 52 **R**: Mitigation of the effects of water restrictions on their lifestyle and enabling people to continue to grow food and gardens under water restrictions (+, ◙) 52, 42 **A**: Improving amenity and property values and improving the taste of water in areas of poor water quality (+, ◙) 52 **H**: Drowning hazard (-, ◙) 16 **H:** Safety net against terrorist attacks (+, ↑, ↓, ◙) 55 **H:** Increased use of rainwater tanks may heighten the risk of waterborne disease outbreaks unless appropriate preventative measures are undertaken. (-, ◙) 32, 58 **E:** Significant reductions in water use, up to 50% (+) 49, 17 **E:** Substantial reductions in nutrient loads to oceans and waterways (reduces phosphorus loads by 68% over reticulated water for a 600L tank) (+,↓) 49 **E:** Significant reductions in NO_x flowing to stormwater systems (+,↓) 49 **NU:** sense of community-mindedness (+, ◙) 52 **O:** it was shown that the use of rainwater tanks provided high levels of economic benefits to the community and individual savings on mains water bills (-) 49, 17 **O:** Useful measure for water demand in emergency cases (+, ◙) 58 **O:** could reduce water and food crisis in some regions – increasing water security, especially important in the event of extreme climatic change (+, ◙) 42, 73, 65
Manufacture	**GHG:** Often tanks and associated plumbing requires high levels of transport throughout stages of manufacture to installation which increases GHG emission and degrades air quality. (-, ◙) 49, 17 **GHG and En:** energy and material impacts of water tanks much higher than water from reticulated water supply (-) (especially when pump is used) (-) 49 **GHG and En:** (PLASTIC) Materials used in the fabrication of plastic tanks is High Density Polyethylene (HDPE), derived from fossil fuels, currently 100% virgin plastic is used (-) 17 **WQ and P:** Reduces combined sewer system overflow and peak stormwater flow pressure (+ ↓) 83, 17 **H:** Carcinogens released throughout manufacture (16% higher than reticulated water for 600L tank) (-, ◙) 49 **H and E:** Higher release of heavy metals through manufacture and disposal (40% higher than for reticulated water) (-, ◙) 49 **H and E:** High levels of photo oxidant chemicals stemming from plastic manufacture (4133% higher than reticulated water for a 600L tank) (-, ◙) 49 **O:** Avoided water storage infrastructure is significant, however, not large enough to offset the impacts of water tank construction and operation (-, ◙) 49
Storage	**P and O:** Reductions in Combined sewer overflow (+, ↓, ◙) 83 **H**: Provision of mosquito breeding sites though risk is very low if tanks are well maintained (-, ◙) 46, 49, 70
Distribution	**En:** Consume energy associated with pumping for internal use though short distance tends to make more efficient than other sources (-) 51
Use (household)	**GHG and En:** Pumps are often oversized and inefficient (-) 49 **WQ and H**: Contamination from atmospheric pollutants including particles, microorganisms, heavy metals and organic substances (-, ◙) 42 **P:** Reduces residential fresh water demands by up to 50% (+, ◙) 17 **P:** Annual cost savings for households ranged from $3 to $223 per year and from $0 to $240 per year for using rainwater both outdoor and indoor uses (+, ◙) 78 **R and A:** Enables watering of gardens under water restrictions(though not in the majority of cases of mandatory tanks installed under the QDC)(+, ◙) 55, 42 **WQ and H:** Catchment surfaces themselves may be a source of heavy metals and organic substances AND bacteria, viruses and protozoa may originate from faecal pollution by birds, mammals and reptiles that have access to catchments and rainwater storage tanks (-, ◙) 42 **A:** Water tanks may impact negatively upon aesthetics of garden space, taking up, on average, $4m^2$ of garden space (-, ◙) 49 **H**: risk of run-off contamination, via direct depositions by birds and small mammals, decay of accumulated organic debris, and atmospheric deposition of airborne micro-organisms, heavy metals from the roof surface and chemical pollutants. (-, ↓, ◙) 30, 42, 44 **O:** rainwater use can work as a kind of environmental education to make citizens aware of sustainable urban water use (+, ◙) 58
Disposal	**H and E:** Higher release of heavy metals through manufacture and disposal (40% higher than for reticulated water) (-, ◙) 49 **E:** Possible substantial levels of solid waste to landfill due to electricity use and tank disposal , around 40% of tanks installed are recycled, 20% of copper used and 50% of the pumps (102% higher than reticulated water supply for a 600L) (-, ◙) 49

3.2. Stormwater Harvesting

Stormwater harvesting (SWH) was investigated as a potential option for the MBRC TWCM Plan – both for improving stormwater quality (via reductions in pollutant loads from catchments due to reuse) as well as an alternative source of water supply (BMT WBM, 2012). An additional, external, benefit is that SWH can help mitigate the increased frequency and magnitude of runoff flows (and subsequent ecological and economic impacts) due to urbanisation. Increased urbanisation in SEQ has created large areas of impervious surfaces, resulting in an increase in the total volume of stormwater runoff (Mitchell *et al.*, 2007; Aryal *et al.*, 2010). Stormwater has high pollutant loading and is a major cause of environmental degradation of urban waterways and adjacent coastal waters (PMSEIC, 2003; Naji and Lustig, 2006; Aryal *et al.*, 2010).

In this section, we present some relevant technical background to help identify the full range of potential externalities associated with SWH and compile an extensive list of impacts that may be associated with this management option. While the solution set investigated for the MBRC TWCM did not focus upon SW treatment some effects related to this aspect are included in the following analysis. In the Plan (BMT WBM, 2012 p.512), SWH is reviewed as "large-scale stormwater harvesting for non-potable use (greenfield sites)" and is part of management Scenario 3 (High intensity). The solution set is considered for five of the MBRC TWCM study catchments –Stanley, Burpengary, Lower Pine, Hayes, and Redcliffe.

Pollutants with the potential for environmental harm include; suspended solids, heavy metals, nutrients and polycyclic aromatic hydrocarbons (Aryal *et al.*, 2010; Greenway, 2010). However, the integration of urban water management with urban water provision has seen the development of new water sensitive urban designs (WSUD) that act to capture and treat stormwater allowing for the beneficial reuse of this resource (Mitchell *et al.*, 2007). Stormwater harvesting is characterised by its ability to amalgamate flood control measures, flow management, water quality improvements, and opportunities to offset mains water for non-potable uses (Lloyd *et al.*, 2002, p. 2).

Increasingly, stormwater is being viewed as a valuable water resource. Stormwater runoff levels from urban areas in SEQ are adequate to supplement or even replace non-potable supply. However, significant storage would be required to provide a reliable supply due to rainfall variation (Hausler, 2006). In typical urban developments, the space required for storage is commonly unavailable and prohibitively expensive. Opportunities may exist for smaller scale harvesting schemes such as an installation at schools or universities to irrigate sports ovals and landscaped areas. Examples of stormwater supply projects in SEQ include the South Bank Stormwater Harvesting and Recycling Centre and the University of Queensland Lakes, both used for irrigation of gardens and sporting grounds.

The primary externalities associated with the urban drainage systems designed to protect of cities from flooding and the transmission of waterborne diseases (Nanbakhsh, 2005) relate to impacts on receiving streams, rivers and oceans (Mitchell *et al.*, 2007). In general, stormwater runoff from human land uses can be not only detrimental to the aquatic eco-systems and biodiversity of receiving waters but can impact on the fishing, aquaculture and tourism industries that depend on high water quality (Taylor, 2005; Brown, 2005).

In relation to stormwater treatment, which is not the focus of study in this report, environmental impacts are often mitigated in Australia by the construction wetlands. The idea is to exploit the biogeochemical cycles that naturally occur in wetland eco-systems, for "treating" wastewater prior to release into the waterways or reuse (Rousseau *et al.*, 2008). As well as treatment wetlands, other WSUD options such as unsealed swales and urban lakes hold water back in the landscape thus reducing velocities and the damaging pulses of stormwater flows (PMSEIC, 2003; Fletcher *et al.*, 2004; WSAA, 2006).

In addition to reducing pollution, stormwater harvesting is able to off-set potable water consumption. A SEQ-based study suggests that stormwater harvesting could reduce, or at least delay, the need for future water infrastructure and associated financial costs and externalities (Tanner, Leinster and Hamlyn-Harris, 2010). As noted, this is also true of the other options considered. In an older study of a housing development in Newcastle, NSW, quite bold claims were made that about 60% of residential water could be supplemented, equating to close to 100% of the total stormwater run-off from the site (Coombes, Argue and Kuczera ,2000). However, stormwater is rainfall dependent and is therefore subject to seasonal and climatic variation – including the vicissitudes of climate change (Environmental Protection and Heritage Council, 2007).

The use of stormwater reduces drainage and detention requirements downstream and relieves pressure on drainage infrastructure during storm events and peak stormwater discharges (Taylor, 2005; Brown ,2005; Naji and Lustig, 2006). Alternatively, using excessive amounts of urban stormwater runoff can be detrimental to stream health. Therefore, stormwater harvesting schemes should be designed with "multi-purpose" considerations to provide a balance between both environmental flow and water quality enhancement and as a potable water supply (Mitchell *et al.*, 2007; WSAA, 2006; Environment Australia, 2002).

A review of the practice on integrated treatment and recycling of stormwater in Australia by the Cooperative Research Centre (CRC) for Catchment Hydrology summarises the positive externalities associated with stormwater reclamation projects. Of seventeen projects studied:

- ten demonstrated a capacity for the improvement/protection of downstream waters;
- six presented with capabilities to assist in flood management;
- four were shown to enhance ecological values on site or downstream;
- seven were used for recreational or visual amenity; and
- four demonstrated to be of educational value (Hatt, Deletic and Fletcher 2006, p.105).

Health implications are important considerations when considering the external impacts of stormwater harvesting. Stormwater runoff contains microorganisms which can be harmful to human health. These microbial pollutants can come from a variety of sources including septic tank leaks, sewer system leaks and domestic animal faeces. The presence of these pathogens can lead to an increased health risk, should users contact the untreated water, for example if they bathed in a treatment pond (Davies *et al.*, 2008). There are also environmental and human health risks associated with the presence of heavy metals and organic micropollutants in stormwater (Mikkelsen *et al.*, 2012).

There are a number of new stormwater collection technologies available, such as; grass swale and strip, porous pavements, infiltration trench and biofilters that, in addition to stormwater containment and transportation, provide treatment. The incorporation of treatment into the collection system has the ability to reduce suspended solids and pollutants from road runoff, hence improving the quality of the water entering the waterways. Where water is diverted into storage the pre-treatment assists in improving water quality to meet reuse standards as well as increasing reducing storage maintenance requirements (Nanbakhsh ,2005; WSAA, 2006).

Negative externalities and indirect financial costs associated with such measures for collecting stormwater include:

- maintenance requirements may be costly to councils or a burden to local residents;
- some collection and treatment systems may impact on the availability of local parking as they require extra area and access adjacent to the curb; and
- there are also exfiltration and evaporation loss associated with the incorporation of swales and biofilters into the collection system. However, these losses have been shown to be minimal (Taylor, 2005).

Other key areas that are likely to configure the nature of external impacts can be identified in the suite of management objectives typically covered in stormwater use schemes (Hatt, Deletic and Fletcher 2006, p.105). Such factors are often not considered directly in capital and operating and levelised marginal cost assessments. These objectives contained externality or spill-over effects include:

- water conservation
- protection/ improvement of downstream waters
- flood management
- enhance ecological value of site and/or downstream
- visual amenity/ recreation value
- education opportunity
- demonstration of innovative water management
- demonstration of cost-effective stormwater management

Taylor's (2005) extensive research on the TBL impacts of urban stormwater harvesting provides a valuable review of relevant effects (see Table 8).

Table 8: Possible TBL Assessment Criteria for Typical Urban Stormwater Projects.

TBL Category (Sustainability "Pillar")	**Impact Description** (Direct financial costs are greyed.)
Financial *(i.e. project costs and values that are relatively easy to express in financial terms)*	The life cycle cost of the project over a given life cycle / span (note that to properly compare alternative stormwater projects, the time period over which the life cycle costing analysis is undertaken needs to be the same). For details on how to calculate a life cycle cost for stormwater projects, see Taylor (2003).
	The equivalent annual payment cost (i.e. the life cycle cost divided by the life cycle / span).
	The total acquisition cost (i.e. the initial capital cost including all costs associated with feasibility studies, design and construction).
	The typical annual maintenance cost (this may include an energy cost component for stormwater reuse projects).
	The cost of land occupied by the stormwater management measure (may include the cost of the land and the cost of not being able to use the land for another purpose).
	Savings associated with a reduced need for reticulated potable water (may include the avoided cost of using mains water as well as avoided costs associated with water supply infrastructure).
	Changes to the value of nearby properties as a result of the project.
	The ability to fund / resource the asset's costs over the whole life cycle.
	Savings associated with a reduced need for downstream stormwater detention (typically only relevant to large stormwater reuse projects that detain stormwater on-site during large storm events).
	Savings associated with a reduced need for maintenance of downstream stormwater infrastructure and waterways (e.g. due to reduced downstream erosion associated with small, frequent storm events).
	Hidden costs (e.g. costs associated with taxes, delays in gaining a development approval, environmental permits, environmental monitoring, environmental management during construction, insurance, etc.).
	Contingent costs (e.g. possible additional costs relating to construction, environmental fines, property damage, legal expenses, etc.).
	Changes to annual property rates of nearby properties due to changes in their value.
	The impact on the rate of sales for lots / houses on new estates.
	The organisation's exposure to financial risk.
Social *(i.e. 'use values' that relate to people's quality of life)*	The impact on the area's general amenity / liveability (a broad social criterion that reflects many of the more specific criteria in this table).
	The impact on the safety of people using the area (e.g. the risk of drowning).
	The impact on the health and well-being of nearby residents who may be affected by disease vectors (e.g. mosquitoes), pests and odours.
	The impact on the area's aesthetic values.
	The intra-generational equity associated with the project. That is, ensuring the benefits and costs of the project to the community are equally shared rather than one part of the community experiencing substantial costs / benefits compared to the broader community (e.g. substantially elevated property values in the immediate vicinity of a public project or disadvantaged disabled citizens as a result of a new design).
	The inter-generational equity associated with the project. That is, ensuring the project produces costs and benefits that are equally shared by current and future generations. For example, ensuring an option does not degrade ecosystems services within a local estuary, so that future generations are unable to enjoy these services.
	The impact on passive and active recreation around the stormwater asset (e.g. walking, jogging, cycling, bird-watching, etc.).
	The impact on individual and community well-being and welfare (e.g. social cohesion and economic prosperity).
	The impact on research and/or educational opportunities (e.g. in association with a constructed wetland).
	The maintenance burden for local residents (e.g. maintaining grassed swales in the road reserve).
	The inconvenience associated with nuisance flooding (e.g. temporarily ponding in swales outside of residential premises).
	The inconvenience to people using the road reserve (e.g. car parking may be restricted due to the presence of stormwater treatment measures).
	The impact on transport opportunities along and/or through the waterway / drainage corridor (e.g. walkways, cycle paths and bridges).
	The impact on the area's cultural and spiritual values (indigenous or otherwise).
	Likelihood of associated behavioural change and/or participation by local stakeholders.
	Flexibility of the project to accommodate changing social expectations over its life cycle.
	The impact on commercial fishing, aquaculture and/or recreational fishing in affected receiving waters.
	The impact on swimming and/or boating in affected receiving waters.
	The impact on tourism and/or water-based transport in affected receiving waters.

TBL Category (Sustainability "Pillar")	Impact Description (Direct financial costs are greyed.)
	The risk of vandalism and/or theft in association with the stormwater infrastructure (e.g. theft of release nets).
	Impact on the availability of shallow groundwater for local reuse.
	Shading / cooling, air quality improvement and carbon sequestration benefits from the use of vegetated stormwater treatment measures (e.g. wetlands, street trees that filter road runoff, etc.).
	The magnitude of GHG emissions associated with the project's power use (potentially relevant to stormwater reuse projects with electric pumps).
	The acceptability to stakeholders of the project.
Ecological *(i.e. non-use that do not relate to the current use of ecosystem services by people)*	The impact on the ecological health of affected local and/or regional ecosystems (i.e. the impact on the "existence value" of these ecosystems). Several secondary criteria and indicators may be developed to assess the likely impact on ecological health. For example, the loads of nutrients entering downstream wetlands could be used as a secondary criterion. In this case the indicator could be kilograms of nitrogen and/or phosphorus per hectare per year, as estimated by modelling. For examples of typical ecosystem health indicators of fresh water, estuarine and marine systems, see the 'Ecological Health Monitoring Program for South East Queensland' (EHMP, 2004).
	The impact on the value of having healthy aquatic and riparian ecosystems for potential use in the future (i.e. the impact on the "option value" of these ecosystems).
	The impact on the value of providing future generations with healthy aquatic and riparian ecosystems (i.e. the impact on the "bequest value" of these ecosystems).
	Ecological impacts associated with the project's materials, wastes and/or energy use during construction, operation, maintenance and/or decommissioning.

Source: Adapted from Taylor (2005)

Stormwater treatment impacts are considered as part of WSUD in the SEQ water management context whereas the MBRC TWCMP study perceives SWH primarily in terms of engineering solutions that use infrastructure to give a high level of purification, prior to pumping the water to some reuse point. There is a contingent management relationship between SWH and natural and other treatment technologies and references to treatment effects are provided with this condition in mind.

The most common method for the treatment of stormwater is to use a natural, constructed, or restored wetland (Rousseau *et al*., 2008; Barten, 1986). A key externality of stormwater harvesting is the use of the inherent treatment properties of wetlands to improve the water quality of stormwater. Wetlands have the ability to remove large amounts of nutrients and suspended solids from flow-through water by using their biochemical properties. Nutrient removal occurs through a variety of processes including filtration, adsorption, ion exchange, biological assimilation, and denitrification (Johengen and LaRock, 1993).

Whilst there are considerable benefits of using natural processes for stormwater treatment, there are some concerns regarding reliability. It has been found that variability in the treatment processes of wetlands can occur due to temperature variation (low temperatures inhibit nitrogen removal), flow variability and the build-up of sediments in the filtrate (Rousseau *et al*., 2008). However, despite this, constructed wetlands have been found to consistently produce water of a high quality particularly in reducing the biological oxygen demand (Rousseau *et al*., 2008; Nanbakhsh, 2005). Wetlands are also highly effective in removing pathogenic organisms and low-concentration compounds such as pharmaceuticals and personal care products and heavy metals (Rousseau *et al*., 2008). A SEQ study of two stormwater harvesting sites showed that, whist the ponds did not consistently achieve water quality objectives, that they were still effective in removing nutrients and suspended solids (Greenway, 2010). Another study, this time from Canada, demonstrated through long-term routine monitoring, that stormwater harvesting usually satisfies water quality guidelines for recreational and irrigation uses (He, 2010).

The utilisation of the natural biochemical processes that occur in the wetlands to treat stormwater results in low operation costs. As most wetlands are gravity fed, the only energy consumption is limited to designs that may require pumping and there are usually no chemicals used (Rousseau *et al*., 2008). Maintenance costs include labour costs, site inspection, effluent sampling, cleaning and weed control and plant harvesting. If wetlands are well maintained they can meet the high standards required for usage in irrigating parks and gardens.

The storage of stormwater has benefits not only for the treatment processes it provides but also the provision of an urban water feature providing a home to wildlife and utility to people as a recreation area. There are however health concerns that must be managed appropriately.

Many of the stormwater basins that have been constructed in urban areas were built to detain or retain urban runoff for flood mitigation purposes. These stores have the potential to be designed to provide both flood protection and stormwater storage for harvesting, whereas offline stormwater stores do not provide flood protection (Greenway, 2010). The design of a store for both supply and flood protection requires careful consideration of the likely level of the active storage portion of the store as this will influence flood mitigation behaviour (Mitchell *et al.*, 2007; Brown, 2005).

Wetlands, urban lakes, ponds and dams have a number of benefits associated with their aesthetic value. When located in urban developments and public spaces these storages provide a space for passive and active recreational activities (Hatt, Deletic and Fletcher, 2006; Rousseau *et al.*, 2008; Brown, 2005; Greenway, 2010). The recreational activities provided by wetlands include walking, picnicking, swimming and boating, fishing, relaxing, and bird watching (Rousseau *et al.*, 2008; Taylor, 2005). These recreational opportunities associated with wetlands have been found to be the most significant economic benefit associated with stormwater harvesting (Taylor 2005, p.12). In addition to recreation, wetlands provide the opportunity for valuable nature education and research (Greenway, 2010).

Wetlands may also increase surrounding property values and rates of sale based on the nature of their aesthetic values (Taylor, 2005). Property values may increase if the property has a direct view of a constructed wetland or through the potential recreational benefits provided for people living in close proximity. However, wetlands also require a substantial area of land, often not available in established urban areas (Hausler, 2006). A literature review of wetlands found a large number of studies documenting the high visitation rate of wetlands. The reasons for their popularity included enjoyment of the vegetation and wildlife as well as the provision of an exercise track with a high aesthetic value (Rousseau *et al.*, 2008). Other case studies found wetland constructions created a strong sense of community, security, and amenity derived from a layout centred on open spaces (Coombes *et al.*, 2002; Coombes, Argue and Kuczera, 2000).

It has also been suggested that the localised and visible nature of stormwater harvesting might increase community stewardship. Potentially increasing the communities feelings of empowerment and engagement with water management in their area (Makropoulos and Butler, 2010).

The benefits provided by an urban stormwater structure depend on its appearance, health, design and maintenance. A degraded water system may in fact decrease property value, particularly for those houses overlooking the facility.

It has been suggested that the implementation of stormwater harvesting in a way which enhances net social benefits might be more effective if public perceptions are explored, understood and incorporated into the project design and implementation (Giacalone, 2010).

Whilst the high loading of nutrients in stormwater run-off may cause anaerobic conditions to develop in storage areas, opportunities for the beneficial use of those nutrients can also arise (Rousseau *et al.*, 2008, p.185). Commercial opportunities for horticulture, such as ornamental plants or plants used for mulching or silage in livestock fodder, are available in constructed wetlands. The plants also sequester carbon during their growth and could potentially be used to obtain carbon credits (Rousseau *et al.*, 2008). Other water quality issues relate to the relatively high levels of salinity. Depending on the design, high levels of evapotranspiration may cause an increase in salinity rendering the effluent unsuitable for irrigation.

Constructed wetlands provide certain ancillary benefits for the provision of a wildlife habitat not only for enjoyment by people, but also as biodiversity and eco-system bequest values (Rousseau *et al.*,

2008; Pitman, 2010). Wetlands are home to mammals, birds, amphibians, reptiles, fish and invertebrates (Greenway, 2010). Concerns that the pollutants in stormwater may spread diseases through visiting fauna and bioaccumulation in certain species have not been realised (Rousseau *et al.*, 2008).

In addition to the non-use values associated with a healthy eco-system, wetlands provide a number of ecosystem services that relate to direct benefits, such as water regulation, water supply, waste treatment, food production and recreation (Tanner, Leinster and Hamlyn-Harris, 2010). Vegetation also provides shading, habitat, and improvements in air quality, urban cooling and aesthetics (Taylor, 2005, p.23; Pitman, 2010).

Wetlands and urban lakes may be a breeding site for mosquitoes that can transmit pathogens such as Ross River fever and malaria. In Australia, Ross River fever is responsible for thousands of cases annually of a disease that is severely debilitating, has high regional incidence rates and costs millions of dollars in health and other impacts. Disease transmission depends on mosquito species and abundance, and extent of contact with humans. The characteristics and siteing of a wetland will determine the hazards and indicate the risk of nuisance and disease.

It is important that mosquito management is integrated into urban wetland design so that health impacts can be minimised (Russell, 1999). Wetland designs that include deeper habitats with cleaner steeper margins, and more open water, produce fewer mosquitoes. Water and vegetation management options to reduce mosquito breeding include aeration and sprinkler systems, along with flooding and drainage regimes, which can reduce larval densities; vegetation thinning can assist mosquito predators. Wetlands with high biodiversity and an extensive food web have also been found to have a low prevalence of mosquitoes (Rousseau *et al.*, 2008, p.185).

As discussed, there are also environmental and human health risks associated with the presence of heavy metals and organic micropollutants in stormwater (Mikkelsen *et al.*, 2012).

A wide range of other potential SWH effects linked to recreational, transport, educational, liveability and aesthetic values, nuisance flooding, and health and safety (e.g. drowning risks) are listed in Taylor's (2005) table.

The externalities that need to be included into water supply evaluations regarding the use of stormwater are the potential health risks associated with the water quality and overcoming social acceptability barriers. To reach the required water quality standard for domestic non-potable use, a high level of treatment, for example membrane filtration and disinfection, is required. The cost of treatment would therefore be significantly higher than for raw water supply from conventional storage. Providing non-potable harvested stormwater for urban irrigation and toilet flushing through dual reticulation can be implemented into the design phase of new developments at a substantially lower cost than retrofitting into existing suburbs. Even so, the NSW Department of Environment and Conservation found that stormwater harvesting is likely to have a higher cost per kilolitre of water than rainwater tanks (Hausler, 2006). However this is not necessarily inhibitive, as the financial costs of rainwater tanks also outweigh the financial benefits.

While likely to be of limited relevant in the SEQ context, constructed wetlands can also serve as infiltration areas for groundwater replenishment; this is known as aquifer storage and recovery or aquifer storage, transfer and recovery. Treatment of the runoff is necessary prior to aquifer storage as irreversible damage can occur to the aquifer. An aquifer storage and recovery scheme should not lead to deterioration of the water quality from an aquifer. The injected water should be of Grade A+ standard. Controls are needed to ensure entrained air and organic matter in the recharged water are minimised to avoid algal growth (Hausler, 2006). By forcing the water through the aquifer, it is expected that the water quality of the recovered water will be improved through natural chemical and micro-biological removal processes (Pitman, 2010).

The full range of externalities identified for stormwater harvesting (including some treatment aspects considered as part of the WSUD in the MBRC TWCM Plan context), and brief descriptions, are presented in the table below. A more specific list of externalities relevant in the SEQ MBRC context are provided in Chapter 4 of this report. The effects have been allocated in accordance with the life-cycle and operational phases in which they are most likely to occur. A general category is also included for effects that are not neatly classified within these phases. The externalities are also identified in terms of more general externality "types" (e.g. GHG emissions, recreation (R), and so forth) as described in the methodology section. For each specific externality, symbols indicate the typical nature of the impact in terms of whether they tend to be a positive (+) or negative externality (-); whether impacts tend to occur predominantly downstream (↓), upstream (↑), or within the immediate surrounds of the supply infrastructure (◙).

Note that most of the biophysical and quantitative socioeconomic data listed in the externality tables for each option (Tables 7, 9 and 11) is not derived from the SEQ or MBRC study context. Hence, this information must be assessed in terms of the need for adjustment and more intensive primary research in the case study areas. However, values are indicative and can, arguably, provide a comparative basis and initial estimate for ongoing research.

Table 9: Stormwater Harvesting Externalities.

LIFE CYCLE OR OPERATIONAL PHASE	
LIFE CYCLE OR OPERATIONAL PHASE	**EXTERNALITY TYPE, DESCRIPTION (showing if positive or negative effect, main location and reference source number)** (See Appendix B for reference source code details) (See inset table to left for externality type codes)
General **Externality Type Codes =>** GHG Greenhouse gas emissions En Energy WQ Water Quality N Nutrients P Production values R Recreation values A Amenity values H Health values E Ecosystem values B Biodiversity values NU Non-use values O Other	**GHG:** Carbon sequestration derived from the application of vegetated treatment measures (+) 79 *(= reference source code; see Appendix B)* **WQ:** Reduction in pollution from stormwater runoff and improved flow regime (+, ↓) 41, 56 **WQ:** Increases in availability of shallow groundwater (+, ↓, ◙) 79 **WQ:** Protects the water quality of the surface, ground and marine waters relative to pre-development conditions (+, ↓, ◙) 84, 31 **N:** Potential to reduce nutrient build up, e.g. phosphorus and nitrogen through filtration, adsorption, ion exchange, biological assimilation, and denitrification (+, ↓) 45 **P:** Can assist in flood mitigation (+, ↓) 56, 14 **P:** Commercial fishing and aquaculture is affected by receiving waters (+, ↓) 79 **P:** Reduced need for detention infrastructure downstream and decreased need for drainage infrastructure maintenance (-, ↓) 79, 14 **P, A, E:** Reductions in the processes leading to the acidification of coastal catchments (+, ↓) 27 **R:** Increased potential for tourism and water-based transport in affected receiving waters (+, ◙, ↓) 79 **R and A:** Potential to provide recreational spaces, i.e. if opt for urban wetland/pond storage systems. (+, ◙) 72, 41, 14 **E:** Potential to enhance ecological value downstream, reduction in contaminants and improved flow regimes etc (+, ↓) and reduced pollutant loads to receiving waters (+, ◙, ↓) 41, 56, 14 **E:** Cooling due to shading, air quality improvement and carbon sequestration benefits from the use of vegetated treatment measures (e.g. street trees that filter road run-off). (+, ◙) 79 **E:** Reduced potable water use (+, ◙, ↓) 27 **E:** Reduced impact of acid sulphate soils (+, ◙) 27 **E**: Reduce the impact of urbanisation on existing natural features and the hydrologic behaviours of catchments (+) 84, 67 **E:** Reductions in waterway erosion and pollution and the lessening of risk of the acidification of soils (+, ◙, ↓) 27 **En, H, WQ, N:** The power and chemicals use required for advanced stormwater treatment (for harvesting schemes) (+, ↓) 54 **NU:** Direct and indirect use values of healthy waterways (esp. aquatic and riparian ecosystems) and maintaining healthy waterways for future generations; and future access to land that stormwater infrastructure occupies (+, ↓, ↑, ◙) 79 **O:** Can assist in flood mitigation (+, ↓, ◙) 56
Collection	**N**: Ability to reduce suspended solids and pollutants from road runoff (+, ↓) 59, 84 **N:** Potential to reduce nutrient build up, e.g. phosphorus and nitrogen through filtration, adsorption, ion exchange, biological assimilation, and denitrification (+, ↓) 45 **P**: Maintenance can be burden on residents (e.g. maintaining roadside swales) (-,◙) 79 **R:** provision of transport opportunities along waterways and drainage corridors (+, ↑, ↓, ◙) 79 **E:** Minimises the impact upon existing natural features ad the hydrologic behaviours of catchments (+) 84, 67 **E**: Decreased erosion (+,↓) 79, 27 **E:** Reductions in litter pollution into waterways (+,↓) 27 **E:** Can interrupt environmental flows to urban rivers and creeks, denying stormwater flows if over-extraction occurs (-, ↓, ◙) 84, 27 **O:** Parking restrictions around stormwater measure (e.g. keeping off roadside swales) (-,◙) 79 **O:** Can assist in flood mitigation (+, ↓, ◙) 56 **O:** Reliant on rainfall which is increasingly unreliable and subject to seasonal and climatic variation- water security implications as supply option (-, ↓, ◙) 29
Treatment	**GHG:** For wetland systems, CO_2 sequestration. (+) 79; may also involve net increases in N2O generation **WQ**: Ability to remove some pathogens, and improve/36elm in the nutrient levels (+,↓, ◙) 72 **WQ:** Increases water quality downstream (+, ↓) 41 **N**: abatement of nitrogen pollution (+,↓, ◙) 17a **E:** Disposal of the waste from the treatment plant may be an issue depending on the location of the plant (-, ↓, ◙) 84 **O:** Stormwater is often of poor quality due to flushed pollutant from roads etc and therefore requires high levels of treatment which is expensive (-,◙) 84

LIFE CYCLE OR OPERATIONAL PHASE	
LIFE CYCLE OR OPERATIONAL PHASE	**EXTERNALITY TYPE, DESCRIPTION (showing if positive or negative effect, main location and reference source number)** (See Appendix B for reference source code details) (See inset table to left for externality type codes)
Storage	**P:** Evapo-transpiration on large scale may lead to increased salinity rendering water unusable for irrigation (-) 72 **P and H:** May be subject to intentional sabotage (-,◙) 29 **P and R:** Education and research asset in form of constructed wetland or pond (+, ◙) 79 **R**: Provides recreational spaces (e.g. swimming and boating) (+) 41, 79 **R:** Improved recreational fishing opportunities (+, ↓) 79 **A**: Increases to surrounding property values and rates of sale by aesthetic value of stormwater ponds/wetlands (+, ◙) 79 **A**: May cause odour nuisance in high loaded systems with anaerobic conditions (-, ◙) 72 **A:** Can provide aesthetic appeal if well designed (e.g. urban wetland/pond systems) and increase capacity for use on aesthetic spaces (parks etc) (+, ◙, ↓) 56, 79, 84 **H**: May provide potential mosquito (disease vectors) breeding sites if poorly designed and maintained (-, ◙) 72, 70 **H:** Drowning hazard (-, ◙) 79 **H and O:** flooding around stormwater retention measures (-, ◙) 79 **B:** Provision of habitat for native flora and fauna (+, ◙) 72, 40 **O**: Potential to assist in flood management (+, ↓) 41 **O:** Storages require substantial areas of land, which are often not available in established urban areas (-,◙)
Use/Distribution	**P:** Recycling rainwater/stormwater achieves the water reduction objective as well as potentially relieving the drainage infrastructure especially in minor storm events. (+,↓, ◙) 58 **P:** Additionally, the potential for a well targeted recycling system to reduce the peak flow design criteria for mains water and sewerage sizing, thus reducing headwork charges for new developments.(+,↓) 58 **E:** excessive harvesting of stormwater could also be detrimental to stream health (-, ↓) 31 **O:** Possible requirement for extensive pipelines to deliver water to areas of use (e.g. sporting fields, toilets etc) though often it is used on site (-)
Decommissioning	**O:** Assumed to have infinite lifespan if well maintained (+) 57

3.3. Wastewater Recycling

This section provides a summary of relevant technical, process or engineering aspects of wastewater recycling, to domestic and industrial uses, for the purpose of identifying relevant externalities that might be associated with this solution set. The emphasis is upon externality impacts and not the private or financial costs and benefits that are directly involved in intentional, fully-informed market transactions.

Wastewater recycling has proven to be one of the most controversial water supply options in Australia. While the reuse of wastewater has great potential, there are many barriers to its adoption. The most significant barrier, one that has been highlighted in recent years in the Australian contexts, is the community acceptability issue – wastewater commonly being perceived as 'toilet tap' water, and also lack of confidence in wastewater management (Shäfer and Beder, 2006). In 2005, 97% of urban runoff and 86% of total wastewater in Australia was estimated to be returned directly into water bodies, meaning only 9 - 14% of wastewater was actually recycled (Dimitriadis, 2005, p.17). Although the data are not recent, Table 10 shows wastewater reuse as a percentage of the total wastewater available.

Table 10: Estimates of water reuse by State and Territory from water utility sewerage treatment plants in Australia 2001-2002.

Region	Wastewater (GL/yr)	Reuse (GL/yr)	Percentage
Queensland	339	38	11.2
New South Wales	694	61.5	8.9
Australian Capital Territory	30	1.7	5.6
Victoria	448	30.1	6.7
Tasmania	65	6.2	9.5
South Australia	101	15.2	15.1
Western Australia	126	12.7	10.0
Northern Territory	21	1.1	5.2
Australia	1824	166.5	9.1

Source: Dimitriadis (2005)

The table above shows that wastewater recycling in Queensland is approximately 11%, which is one of the higher uptake rates in Australia. The majority of the wastewater produced each year in SEQ is directly discharged to rivers and estuaries (Gardner, 2002). This can result in 'unplanned' water recycling, in which recycled water is used by communities downstream inadvertently (Bixioa *et al.,* 2008). Wastewater discharge is high in nutrients that damage aquatic eco-systems and cause algal blooms (Toze 2004). Considering the high population growth predicted for SEQ, this amount of wastewater produced, and stress on related waterway, ecosystem and other services is set to rise substantially. Wastewater recycling has the potential to reduce the discharge of effluent into waterways an externality that may be costed in terms of the environmental, social and economic benefits provided by the reduced discharge.

In the SEQ and MBRC context, there is a large Class A+ scheme at Pimpama (on the Gold Coast) and a minor Class A+ water scheme operating from the South Caboolture STP. Murrumba Downs (also in the MBRC area) has industrial reuse of Class A+ water. The Western Corridor Recycled Water Project (WCRWP) (AUD$2.5 billion) is Australia's largest water recycling scheme and the third-largest advanced water treatment project in the world and was intended to implement indirect potable wastewater reuse at a large scale but is currently only used for industrial purposes.

There are a series of key positive externalities of wastewater reuse. Firstly, it can reduce damage to aquatic eco-systems, as wastewater is reused rather than discharged to rivers and oceans (Asano, 2001). In addition, the supply of wastewater reduces dependence on high quality surface water. This then retains surface water and groundwater for environmental flows (Hurlimann, 2007; Davis, 2006;

Brennan *et al.*, 2003; WSAA, 2006). Although national average statistics are likely to be of limited direct relevance to the SEQ context, the potential for wastewater to reduce reliance on potable resources has been estimated to be up to 50% of urban water use in Australia as well as providing a valuable resource for irrigation (Dimitriadis, 2005, p.17).

There are many negative externalities associated with the impact of wastewater discharge on the eco-systems and biodiversity of receiving waters. The high nutrient levels in wastewater have been found to encourage eutrophication and be associated with toxic algal blooms. In addition to the high concentrations of nitrogen and phosphorus in wastewater, negative impacts of other chemicals on aquatic biota have been identified over a range of eco-systems. These impacts include pathological tissue changes; estrogenicity and other endocrine disruptions; altered dynamics of populations exposed to sewage; shifts in production and body-size spectra of communities; reduction in seagrass with knock-on effects on food webs; and changes to assemblage composition and structure (Schlacher *et al.*, 2005, p.570). In addition, toxic metals found in wastewater discharges have also been found to cause biological contamination. Indications of physiological stress in animals contaminated with trace toxicants have also been observed (Luoma and Cloern, 1982, p.137).

The change in water quality of a river and ocean also affects its uses for other important social and commercial purposes. Fisheries and livestock watering may be negatively impacted by the increase in nutrient loads to the river. Recreational uses may also be affected. Reducing the release of effluent into coastal waters means less concern associated with contamination of bathing water and aquatic eco-systems (Dimitriatdis, 2005, p.18).

A significant potential source of externalities for wastewater recycling is the energy requirements for (additional) wastewater treatment and pumping energy. SEQ's WCRWP is estimated to have an energy-intensity of 2.45 MWh/ML in comparison to around 0.5 MWh/ML for many conventional dam sources in the region (Hall *et al.,* 2009). If energy sources are primarily fossil carbon-based (as they are in the study region), then this has a host of potential external effects such as GHG emissions and energy vulnerability.

It is important to note that wastewater treatment will occur regardless of recycling uses. However, some of the relevant effects are still reviewed briefly as alternate water sourcing options may affect the level of use of these systems.

The collection of wastewater is commonly achieved via a sewerage reticulation comprised of gravity sewer pipes and pressurised pumping mains. The collection system has energy requirements for the construction, pumping, maintenance, and disposal stages (Dimitriadis, 2005). Wastewater from manufacturing and industrial operations such as food processing or metal refining is known as "industrial" or "trade waste" and may require treatment prior to discharge into the sewerage reticulation. Sources of trade waste include liquid waste from any process, for example, water used to cool machinery or clean plant and equipment. Trade waste requires careful management to ensure that contaminated waters do not enter the stormwater system (Environmental Protection and Heritage Council, 2007).

All recycling approaches will use power and chemicals to some degree and hence will implicate related external effects. Depending upon the choice of reuse approach and level of treatment, this solution set could have a notable indirect GHG footprint associated with the supply of process chemicals and general materials. Also contingent upon technological options adopted, the GHG intensity of wastewater recycling is likely to be higher than conventional potable supplies, but lower than for seawater desalination. Within that band, the power use is likely to vary greatly. The GHG intensity of wastewater recycling systems is highly variable and subject to considerable uncertainty.

Other externalities associated with water recycling use micro-filtration (MF) and reverse osmosis (RO) membranes (not commonly used for Class A+ treatment) are the environmental effects associated with the fouling and cleaning chemicals used to clean the membranes. If released into the environment, these chemicals can cause degradation to ecosystems and biodiversity in surrounding areas. The choice of

chemicals needs to be sensitive to the characteristics of the receiving environment. (Beyer, Lohrengel and Nghiem, 2010). For technologies other than MF and RO, chemical use will be intensive, but it is unlikely that they will be discharged into waterways in significant quantities.

Bixio *et al.* (2010 p.7) outline some of the major risks and constraints associated with the use of recycled water for different environmental and economic purposes:

- Agriculture – presence of pathogens, possible pollution of the soil and aquifers; salinity, toxicity; acceptability of the product on the market.
- Urban – microbial growth, slime/scale formation and foaming, corrosion, deposition/clogging, staining.
- Industrial – presence of pathogens, corrosion, deposition/clogging of the distribution system; hazards related to possible cross-connection with potable water supply.
- Environmental – presence of pathogens, possible pollution of the aquifer, eutrophication, toxicity.

Wastewater use can offset the use of surface water for a number of purposes including; the provision of a source of water for non-drinking purposes such as commercial and industrial processes; for primary production; irrigating parks, gardens and other open spaces; aquifer recharge; and to supplement surface water supplies (Dimitriadis, 2005). Wastewater is a reliable and constant supply option which is independent of rainfall and has provided support for numerous drought-constrained regions (Pasqualino, 2010; WSAA, 2006; Angelakis, Bontoux and Lazarova, 2003). An example of this is a dairy farm in Shoalhaven, NSW that used urban wastewater to survive a drought period (Dimitriadis, 2005).

There are a number of externalities associated with the use of recycled water for agriculture. When used for irrigating crops the high nitrogen and phosphorus content can reduce the need for fertiliser (Dimitriadis, 2005; Toze, 2004; Angelakis, 2003). Recycled water can increase agricultural productivity; however, due to the higher concentrations of nitrite, ammonia and organic nitrogen found in wastewater, it also increases the likelihood of certain water quality problems. Additional nutrients can provide a source fertiliser but can also have adverse effects through excessive microbial activity which may cause detrimental impacts on soil porosity (Toze, 2004). There is a potential for the generation of nutrient and contaminant high runoff reaching waterways, nutrient and contaminant build-up in soils and possible contamination of groundwater if recycled water is applied inappropriately (PMSEIC, 2003; Schäfer and Beder, 2006).

The chemicals potentially found in wastewater may pose a risk when used for stock and agriculture. Water quality issues that can create real or perceived problems in agriculture include; nutrient and sodium concentrations, heavy metals, the presence of human and animal pathogens, and pharmaceutical and endocrine disruptors (Dimitriadis, 2005, p.25: Toze, 2004, p.4; and Jang *et al.*, 2010). Societal attitudes to crops that have been irrigated with recycled water and the resulting impact on market values are also a major consideration. Salinity present in wastewater is expensive and difficult to remove and can have serious implications particularly for irrigated crop species with a low salt tolerance (Schäfer and Beder, 2006, p.246).

Recycled water has also helped to maintain greenspaces and gardens in urban and rural centres (Ongerth and Ongerth, 1982). The use of recycled water for urban spaces during drought periods may increase tourism and recreation, for example, the irrigation of golf courses and gardens.

A major externality (than can be estimated in market terms via risk analysis approaches) of recycling wastewater is that, like desalination, it is relatively climate insensitive and hence resilient to climatic variability and climate change, in comparison to rainwater-based alternatives such as dams, rainwater tanks or stormwater harvesting).

Although perhaps of limited relevance to the MBRC context, recycled water offers potential benefits for restoring wetlands and other natural habitat by eliminating or reducing overdraft of groundwater

supplies (Davis, 2006). However, groundwater recharge with reclaimed municipal wastewater presents a wide spectrum of technical and health challenges that must be carefully evaluated prior to undertaking (Asano and Catruvo, 2004).

Wastewater can also be mixed back into dams and groundwater aquifers to supplement drinking water supplies subject to its quality, appropriate management and control (Angelakis, Bontoux and Lazarova, 2003; Price *et al.,* 2011; Uhlmann *et al.,* 2011; WSAA, 2006; Zhou *et al.,* 2009). This is the most controversial use of recycled water due to potential health impacts. Recycled water can be a source of enteric pathogen contamination e.g. viruses, bacteria, protozoa, nematodes and helminthes (Asano, 2001; O'Toole, Leder and Sinclair, 2007; Toze, 2006). Storing the wastewater in aquifers, may decrease the pathogens in the water (Page *et al*, 2010). Other water quality factors of concern include: total mineral content (e.g. total dissolved salts), heavy metals, pharmaceuticals like antibiotics and pain killers (e.g. paracetamol), radionuclides (e.g. chemotherapy by-products), and concentrations of stable organic substances, pesticides, hormone-affecting and cancer-causing compounds excreted into the sewerage system (Dimitriadis, 2005). These chemicals pose a health risk, particularly if water is to be considered for drinking.

The risk of human exposure to recycled water is related to possible inhalation of aerosols; ingestion through drinking or eating raw food crops irrigated with recycled water; and skin contact, usually through working with recycled water (Ongerth and Ongerth, 1982). Due to these risks, it is important to address water quality issues and usage through stringent guidelines (Asano, 2001).

In addition to the biological risks, concern has also been raised regarding the pharmaceutically active residuals and endocrine disrupting chemicals (EDCs) that may be found in wastewater (Toze, 2004). These compounds have been found to be only partially removed during conventional sewage treatment processes due to their typically high water solubility and, in some cases, a resistance to aerobic biodegradation (Nghiem *et al*., 2004). A number of synthetic organic chemicals pose a health threat. Some of these chemicals are carcinogenic, even in trace concentrations, when ingested over long periods of time. These health concerns are particularly relevant for potable reuse (Ongerth and Ongerth, 1982).

There is a risk of potential loss of fertility and other human functions that could result from the presence of an ever increasing number of designer pollutants and drugs in the water supply (Schäfer and Beder, 2006). Investigations into advanced water treatment technologies suggest that reverse osmosis and nanofiltration may be an effective means of removing the widening range of pharmaceutically active residuals and hormones from treated sewage (Khan *et al*., 2004). However, nanofiltration may not be a complete barrier to micropollutants such as hormones (Nghiem *et al.*, 2004; Le-Minh *et al*., 2010). In view of a growing list of potential contaminants, the scientific community may be behind in terms of being able to accurately measure their presence or the potential health risk (Davis, 2006). Recycling water may not be an effective barrier to the accumulation of persistent antibiotics. This could potentially lead to the development of increased strains of resistant bacteria (Le-Minh *et al.*, 2010).

The mismanagement of recycled water schemes has also been identified as a potential health risk. This specifically relates to the plumbing of recycled water schemes. A number of cross-connections between domestic recycled water and potable water supplies have been recorded (PMSEIC, 2003; Hambly *et al*., 2010) and there are cases of recycled water being ingested and causing illness in Australia (for example, see Brown, 2009).

Although it is not strictly an externality, fear of external effects from the use of recycled wastewater is a major factor affecting its community acceptance and ongoing profitability and net overall social benefit. Most of these fears are related to health concerns. A survey by the Urban Water Security Research Alliance (Qld) analysed the acceptability by the community of indirect potable reuse in SEQ. The survey confirmed a high level of support for drinking purified recycled water (74%), however a number of issues were highlighted regarding trust, the fairness of the scheme, and the operational risks involved (Nancarrow *et al*., 2007, p.6). The main barriers to water reuse in Australia have been identified as lack of public confidence, health, environmental concerns, reliable treatment, storage, economics, the lack of

relevant regulation, poor integration in water resource management and a lack of awareness (Dimitriadis ,2005, p.10; Pasqualino *et al.*, 2010).

An important study of perceptions of recycled water, in SEQ, revealed a number of important factors influencing community acceptance of water recycling. All participants who took place in the survey (conducted by post in Pine Rivers Shire) communicated that they felt as though they were inadequately informed to make decisions regarding water recycling. Participants were also aware of the water shortage at the time and were generally happy for the government to implement water recycling without a referendum (Miller and Buys, 2008). Another study from Wollongong demonstrated that providing increased information and facilitating learning and discussion amongst the public, increased the likelihood of acceptance (Hampton, 2010).

Equity issues are raised in regards to the provision of recycled water. Should water recycling be adopted, people in higher income brackets have the ability to purchase drinking water, while lower socio-economic groups less able to do so (Nancarrow *et al*., 2007; Miller and Buys, 2008). Another way equity issue concerns the tendency for wastewater treatment plants to being disproportionately located in low-income neighbourhoods (Davis, 2006).

A commitment to environmental sustainability includes the desire to capture and reuse all the natural and human wastes generated at a site, including suspended solids and sludge from wastewater treatment and stormwater effluent (AWA, 2010). The capture of onsite stormwater reduces discharge and runoff to the environment by capturing water and nutrients that may otherwise be discharged from wastewater treatment plants (PMSEIC, 2003).

Production of wastewater which is high in nutrients provides the opportunity for the recovery of nitrogen and phosphorus. Phosphorus, in particular, is a finite resource and sought after for use as a fertiliser. One example in SEQ is struvite, which is produced as a commercial fertiliser at the Oxley WWTP in SEQ from nutrients found in biosolids. This industrial ecology option helps to lower the nutrient content of biosolids currently going to landfill (and the related potential to contaminate groundwater as leachate). Phosphorus is a non-renewable resource currently being sourced from phosphate rocks. Recycling of phosphorus from sewage back into a source for plant growth may be increasingly important in the future, should traditional stocks become depleted. Hence, while wastewater recycling for agriculture could help displace synthetic fertiliser use, effluents in SEQ (and the MBRC area) are typically quite low in nutrient concentrations and may have not be viable for significant crop fertiliser application.

There is a paucity of research investigating the TBL impacts associated with the decommissioning phase of waste water recycling.

The range of identified externalities related to wastewater recycling are presented (with brief descriptions) in Table 11 below. A more specific list of externalities relevant in the SEQ RBMC context is provided in Chapter 4 of this report. The effects have been allocated in accordance with the life-cycle and operational phases in which they are most likely to occur. A general category is also included for effects that are not neatly classified within these phases. The externalities are also identified in terms of more general externality "types" (e.g. GHG emissions, recreation (R), and so forth) as described in the methodology section. For each specific externality, symbols indicate the typical nature of the impact in terms of whether they tend to be a positive (+) or negative externality (-); whether impacts tend to occur predominantly downstream (↓), upstream (↑), or within the immediate surrounds of the supply infrastructure (◙).

Note that most of the biophysical and quantitative socioeconomic data listed in the externality tables for each option (Tables 7, 9 and 11) is not derived from the SEQ or MBRC study context. Hence, this information must be assessed in terms of the need for adjustment and more intensive primary research in the case study areas. However, values are indicative and can, arguably, provide a comparative basis and initial estimate for ongoing research.

Table 11: Externalities associated with Waste Water Recycling.

WASTEWATER RECYCLING (Centralised)	
LIFE CYCLE OR OPERATIONAL PHASE	**EXTERNALITY TYPE, DESCRIPTION (showing if positive or negative effect, main location and reference source number)** (See Appendix B for reference source code details) (See inset table to left for externality type codes)
General **Externality Type Codes =>** GHG Greenhouse gas emissions En Energy WQ Water Quality N Nutrients P Production values R Recreation values A Amenity values H Health values E Ecosystem values B Biodiversity values NU Non-use values O Other	**WQ, E and B:** Avoiding degradation of receiving waters (e.g. pollution of streams and saltwater habitats) (+,↓, ◙) 23a, 4 **P:** Support for drought constrained farming (+,◙) 74, 12 **P**: Risk of soil contamination due to build up of water residues (Salinity, boron etc) (-,◙) 74 **R and O:** Enables people to maintain activities requiring water, e.g. garden maintenance, whilst not promoting water waste (-,◙) 23a **H:** Risk of contamination and consequent health issues (-,◙) 74, 64 **H**: Risk of cross-connections leading to contamination (-,◙) 13 **H:** Potential source for enteric pathogen contamination (e.g. viruses, bacteria, protozoa, nematodes, and helminths) (-,↓, ◙) 82, 5 , 64 **H:** Recycled water can contain relatively high levels of EDCs (Endocrine Disrupting Chemicals). Whilst relatively low risk for humans due to low concentrations it has been demonstrated that there can be significant impacts on wildlife that are in constant or near constant contact with the water receiving the treated effluent. (-,↓, ◙) 82 **H, P and B:** risk of pathogenic contamination of treated effluents are unknown, such as the long-term exposure of wildlife, cattle or humans to persistent organic pollutants with more subtle and less immediate effects — from cancer to endocrine disruption. (-,◙) 74 **H and O:** sewage farm workers and their families may experience more serious health risks, this creates equity issues. (-, ◙) 5 **H:** risk of accidental construction faults leading to leakages, contamination or leaching AND risk of purposeful sabotage or damage (-, ◙) 20 **E:** Reduces the discharge of harmful effluents into receiving environments where they can cause eutrophication and algal blooms. (+,↓, ◙) 82, 4 **E:** prevention of coastal pollution (+, ↑, ↓, ◙) 4 **E:** reduce pressure on the highly stressed deep groundwater levels and recover pressured aquifer systems (-,↓, ◙) 12 **B:** Protecting aquatic species by avoiding additional diversions from streams, and rivers (-,↓, ◙) 23a **NU:** community perceptions of risk and disempowerment (-,◙) 24, 53, 60 **O:** offers reliability benefits, since it is available even in drought years. (+,↓, ◙) 21, 24 **WQ and E: R**eduction of the overdraft of groundwater supplies (+, ↑, ↓, ◙) 23a, 12 **O:** High level of community mistrust and perceived risk surrounding potable reuse and uses with high levels of personal contact. Non-potable reuse indicated as top preference (by sample study in SEQ) for water supply. (-,◙) 53, 50, 75 **O:** As with all 3 options, WW recycling diversifies water sources and therefore strengthens water security. (+, ↑, ↓, ◙) 84
Collection	**H:** Potential contamination from industrial and agricultural discharges (-,↓, ◙) 29 **E:** When stored on site, risk of leakage under storages, leading to pollution of groundwater and possible lateral flow to the adjoining streams (-,↓, ◙) 12 **E:** Reduces discharges and runoff to the environment by capturing water and nutrients (+,↓) 84, 67 **E:** Risk of excessive recharge and transport of solutes to the groundwater system (-,◙) 12 **E and O:** When used to irrigate agriculture, significant areas of land are required to store the water when crops do not require it. In addition, there will be significant costs associated with installing the infrastructure to enable delivery to agricultural areas (from mostly coastal urban centres). (-,◙) 84 **O:** Constant and reliable supply (+) 82, 4 ; less dependent upon rainfall and hence better climate change resilience (+, ↑, ↓, ◙)84
Treatment and Disinfection	**WQ and H**: Water quality risks include, increased prevalence of disease-causing organisms; total mineral content; heavy metals; pharmaceuticals; SOCs; radionuclide's and concentrations of stable organic substances. (-,↓, ◙) 24, 63,23a **P:** Using recycled wastewater for irrigation can reduce the need for fertiliser thanks to the nutrients it contains. t (+) 4 **P and E**: Salinity is persistent in recycled water as it is expensive and difficult to remove. Salinity can have direct negative effects on soil properties (-,◙) 82 **H:** Risk of potential loss of fertility or other human functions that could result from the presence of an ever increasing number of designer pollutants and drugs in the water supply (mostly an issue with potable water reuse) (-,↓, ◙) 74 **O:** High levels of community support for recycled water, until it comes physically closer to them, people maintain concerns about drinking and being in close contact with recycled water. (-,◙) 82

4. RESULTS

A detailed and systematic list of the potential externalities for the three solution sets investigated for total water cycle management (TWCM) planning in the Moreton Bay Regional Council (MBRC) have been presented in Tables 7, 9 and 11. These effects encompass quite a broad range of potential option variations and settings and not all will be significant in the MBRC context. It is difficult to ascertain their relevance within the study setting without further detailed research. However, an initial assessment of this relevance has been completed within the resource constraints of this project, and the results are provided in the previous chapter and in this section.

4.1. Externality Analysis in TWCM Planning

Three main sets of information are provided as a foundation for future research assessing the desirability of water management scenarios from a comprehensive societal point of view. This approach comprises a more realistic view of project impacts by highlighting the need to anticipate and plan for the effective range of economic, environmental and social effects and interactions which are intrinsic to the human-environment relationship.

As discussed in the introduction of this report, TWCM approaches are based on recognition of close interconnections or strong "ecological" relations between society (and its component economic activities) and the integrated processes of water and other natural cycles. This interdependence cannot be ignored and will inevitably have significant consequences for net community economic and social welfare outcomes of major interventions related to water management. "Holistic frameworks" and "integrated management" are the catchcry of the future and externalities are the essence of this web of inter-connectedness. The research described in this report is a step towards pre-empting this future focus.

Externality analysis and valuation methods that cover a broad range of TBL impacts are consistent with a social cost-benefit analysis (CBA), or at least an "extended" cost-effectiveness analysis (CEA) approach. They have great potential for expanding the potential of a CEA approach focused upon water savings and yield and pollutant load reductions (as adopted in the primary research document assessing TWCM options and devising an appropriate strategy plan for the MBRC (see BMT WBM (2012)). Essentially, the mixed CEA and multi-criteria analysis research method of the MBRC TWCM Plan is predicated upon expected financial (capital and operating) costs, modelled water quality and water savings outcomes, some analysis of connections between options, followed by decision-making from a selected group of expert and stakeholder knowledge and preferences regarding option feasibility and the desirability of anticipated outcomes for a number of economic, environmental and social criteria outcomes.

The potential role of externality analysis and valuation in CBA, CEA and MCA, and decision-making in general, is discussed in some detail in Daniels, Porter and Bodsworth (2012). This also covers the limits of these alternative approaches. As a minimum offering, externality analysis and valuation provides useful information about the full range of effects and community welfare changes represented by trade-offs that people demonstrate or state in evaluating outcomes. This is a valuable data feed into any subsequent decision-making framework – including criteria selection, scoring and weighting in MCA.

Of course, the ability to analyse an expanded range of external effects requires adequate knowledge of the main relevant interconnections within and between environmental and socioeconomic systems. It also needs, as a basic pre-requisite, the fundamental biophysical or at least quantitative measures as per Step 3 of the SEXTAN methodology – that is, "for each option in the scenario, the biophysical or socioeconomic (non-monetary) quantification of each externality generated per unit output of required water quality from that option." To compare the full social costs and benefits of proposed management scenarios, this information is required for: (1) existing water servicing conditions; and (2) new solution set mix/ management scenarios. Unfortunately, few data are available beyond the financial costs of achieving target outcomes.

CBA methods require estimation of the full range of benefits of each option. However, in CEA as adopted in the key MBRC plan study, the benefit structure of options considered is internalised in the choice of targets. This assumes away the need for the detailed analysis of benefits in order to compare options. Costs are only really considered as the financial capital and operating costs of getting to the assumed optimal (from society's point of view) externality level. Hence, the only externalities included in the main TWCM study for the MBRC are water quality pollutant loads (TSS, TP, TN), and to some extent, incidental water savings and supply changes contributing to the QDC MP 4.2 alternate water supply target. There is also a general analysis of total GHG emissions associated with each management scenario and catchment.

There are good reasons why data for more extended externality analyses are limited – the required research is often resource-intensive of uncertain cost-effectiveness. However, relevant conceptual, methodological and data capabilities (including accumulated knowledge and database feeds) are growing strongly and will continue to facilitate better analyses in the future.

In this section, we complete initial groundwork and data feeds for Step 2 of the simple externality analysis (see Box 2) – the main externality identification tables provide major guides and information feeds. It also provides a summary of the external effects that are likely to be most relevant to the TWCM solution sets in the MBRC context as well an extensive compilation of valuation estimates for Step 4 in the externality analysis procedure. As discussed, Step 1 is completed in the initial strategic planning process and Steps 3 requires scientific research and technical understanding to identify biophysical and other quantitative dose-response relations associated with the water servicing option, or "solution set" under study (which is limited in the study context at present).

Box 2 – Steps in the Simple Externality Analysis (SEXTAN) Method

STEP 1: Scenario composition based on the contribution of component water supply options.
STEP 2: Given the options comprising each scenario, identification of the major externalities associated with these options.
STEP 3: For each option in the scenario, the biophysical or socioeconomic (non-monetary) quantification of each externality generated per unit output of required water quality from that option.
STEP 4: The economic valuation of relevant *per unit* biophysical or indicator externality impacts (typically biophysical) for *each* option.
STEP 5: Calculation of *each* externality type's cost/benefit *per unit* water service change.
STEP 6: Calculation of the total dollar value cost or benefit of each externality effect from the *total* planned change in water service.
STEP 7:. Include the externality valuation results into decision-making processes; either separately for each externality impact or aggregated in various ways for the alternatives being assessed.

Source: Daniels, Porter, Bodsworth (2012)

4.2. Main Externalities Relevant to the Focus Solution Sets

The externalities likely to be most relevant to the three solution sets that have been investigated from the MBRC TWCM Plan are compiled in Table 12.

Table 12: Summary table of the key externalities associated with the three solution sets investigated for the MBRCP TWCM management scenarios.

STORMWATER HARVESTING	
• Reduction in pollution, decreased nutrient to waterways from stormwater runoff, leading to downstream economic, social and ecosystem benefits (Collection and Treatment Stages) • Provision of recreational spaces (when incorporating wetlands or ponds). (Storage Stages) • Enhanced flood mitigation. (Storage Stages) • Possible increases in surrounding property values, stemming from amenity benefits of water bodies. (Storage Stages) • Potential health concerns – e.g. mosquito breeding sites, pathogens, organic chemicals, heavy metals; and drowning hazards. (Storage Stages) • Fauna and flora benefit through aquatic habitat provision. (Storage Stages) • Chemicals usage for treatment and product water distribution • More energy-intensive than conventional mains supply • Risk of soil contamination (if used for irrigation) (Use Stages) • Risk of cross-contamination and consequent illness. (Use/ Distribution Stages) • Decreased mains water use, which will offset externalities from those sources and may defer the need for additional water infrastructure. (Use Stages)	**Main Externality Types** Nutrients (N), Recreation (R), Ecosystem (E) **Valuation Examples** ($AUD 2010) Improvement to Environmental Flows $57.54 per household (hh)/yr (ref no. 11) Mean WTP for wetlands $45.56/cap/yr (ref no. 61) Value of habitat/recreation area provision $32.1 mill/yr (ref no. 62)
RAINWATER TANKS	
• Reduction in pollution to waterways from stormwater runoff, leading to downstream economic, social and ecosystem benefits (Collection and Treatment Stages) • Comparatively higher energy usage than reticulated mains water (mostly due to inefficient pump systems). (All Stages) • Higher GHG emissions than reticulated water. (All Stages) • Enables gardening and home food production to occur despite drought conditions and water restrictions (this leads to amenity and recreational benefits). (Use/Distribution Stages) • Decreased mains water use, which will offset externalities from those sources and may defer the need for additional water infrastructure. (Use Stages) • Decreased pressure on drainage infrastructure in flood events. (Collection and Storage Stages) • Potential contamination risk leading to negative health consequences. (Storage and Use Stages) • Possible mosquito breeding site if poorly maintained. (Storage Stages) • Waste disposal is a potential source of pollution and environmental and health contamination risk (Disposal Stages)	**Main Externality Types** GHG emissions, Health (H),Ecosystem (E) **Valuation Examples** ($AUD 2010) GHG: vary from $5.94 to $177.43/tonne CO_2 WTP to avoid waterway degradation $184.73/person/yr (ref no. 79)
WASTEWATER RECYCLING	
• Reduced pollution of receiving waters. (Collection and Treatment Stages) • Additional water resource available to drought constrained farmers and other industries. (Collection and Use Stages (+,◙)) • Risk of soil contamination if used for irrigation. (Use Stage) • Contamination risks and associated health concerns. (Treatment and Use, Distribution Stages) • Low levels of community acceptance and increased social conflict for 'high-contact' uses (Use Stage) • Agricultural reuse has potential to reduce the need for synthetic fertiliser use (Use Stage) • Increased capacity for maintenance of 'green spaces' throughout droughts – amenity and recreational benefits. (Use Stage) • Disposal of concentrate (a by-product) may lead to environmental degradation and/or high transport requirements • Enables gardening and home food production to occur despite drought conditions and water restrictions (this leads to amenity and recreational benefits). (Use/Distribution Stages) • Power and chemicals use for treatment and product water (Treatment stage)	**Main Externality Types** Water Quality (W.Q),Production (P), Health (H),Non-Use (N.U.) **Valuation Examples** ($AUD 2010) Cost of a visit to emergency room $488.52 (ref no. 346) WTP , – $70.35 per household (hh) per year to be compensated for recycled water with high contact uses (ref no. 36) $1073 for annual phosphorus load reduction (ref no. 3)

4.3. Existing Externality Valuations for the Three TWCM Solution Sets

Table 13 provides a detailed compilation of existing monetary valuation estimates for the external effects relevant to three of the solution set options from the MBRC TWCM Plan (as completed in the identification process in Chapter 3). These valuations were gleaned from a diverse range of existing environmental economic research. Details of the relevant economic valuation techniques (and their links to TEV types and the externality effects) have been provided in the previous two reports by the authors (Daniels *et al.,* 2012; Daniels, Porter, and Bodsworth, 2012). The original estimates have been converted to 2010 Australian dollar equivalents in order to facilitate ready comparison. They are presented for use in a general "transfer benefits" sense, where the estimates can be considered as indicative and subsequently used with qualification or with modification based on known local conditions. Values will vary considerably across geographical settings and with different technologies and modes of operation. Of course, they can be rejected or simply used as comparative measures when primary research is possible or required given unique or very different contextual settings.

Table 13: Existing valuations for externalities associated with the three solution sets investigated for the MBRCP TWCM management scenarios.
(Sorted by Externality Type)

Externality Type	$AUD (2010)	Year of Study	Reference source (see Appendix B for reference details)	Explanation/Comments
1. Pressure or State Change Indicators				
GREENHOUSE GAS EMISSIONS (CO_2 only, $/t CO_2)				
	$23	2012	Aust Govt (2012)	This is the initial working price (implied cost) for a tonne of carbon for Australia's Clean Energy Plan. It is fixed at A$23 per tonne for the 2012–13 financial year and will then rise by 2.5% a year, until a transition to an emissions trading scheme in 2015–16.
	$28.54 – 42.81	2002	18	The best guess data have a median value of $22t/ CO_2 /tC (28.54), an average value of $33/tC t/ CO_2 (42.81) with a standard deviation of $38t/ CO_2 , a minimum of -$19t/ CO_2 and a maximum of $210.t/ CO_2
	$60.3	2002	19	It has been estimated that the global cost of meeting Kyoto targets would be around £45t/ CO_2 (60.30) (2000 prices).
	$116.39	2008	71	To enable 20% CO_2 emission reductions by 2020 price would rise to $100t/ CO_2 (116.38) by 2020.
	$21.92 – 30.35	2008	48	CPRS-5 $20.88/t CO_2in 2010 (21.92) and CPRS-15 $29.10t/ CO_2 in 2010 (30.35) both increasing by an average of 4% a year to 2100.
	$20	2010	15	The Greens propose two-year fixed price of $20/t CO_2rising each year following that by 4% plus the increase In the consumer price index.
	$70.82	1996	43	A value in the region of US$45 to 50/t CO_2 (70.82 – 78.68) would correspond to around I p/kWh for electricity generation using conventional coal technology, a significant fraction of generation costs.
	$19.22		1	From $18.30/t (19.22) CO_2in 2010 to $50.20t/ CO_2 in 2030.
	$26.25	2008	48	Garnaut-10 begins at $25/t CO_2in 2013 (26.25) and Garnaut-25 $45/t CO_2in 2013 (47.25).
	$65.4	2007	25	$60t/ CO_2 (65.4) would encourage greater uptake of bioelectricity.
	$24, $33.6, $42	2008	6	CPRS prices between $23 (24.15) and $32 (33.6) at the start of the scheme, 'the government considers a price cap of $40 (42) is appropriate in balancing these requirements".
	$21 – 31.50	2008	34	Garnaut Report. Between CO_2 by 2013.
	$31.54	2010	*66*	International aggregate data. €21/t CO_2*is an average fair price assessment for 2010-2012 EUAs provided by Point Carbon's Carbon Market Trader. Last updated 05.02.2010. Change relates to 17.12.2009.*

Externality Type	$AUD (2010)	Year of Study	Reference source (see Appendix B for reference details)	Explanation/Comments
Existing Permits/ Credit Schemes	$17.44		80	Retailers can purchase CO_2 credits for $16/t CO_2 (17.44) (in Aust).
	$12.87		79	BP allocates $11/t CO_2 (12.87).
	$40.44	2007	52	Sydney Water, estimated cost per tonne $37.18 t/ CO_2 ($40.44) (through renewable energy certificates).
GREENHOUSE GAS EMISSIONS (Social Cost of Carbon)				
Social Cost of CO_2 (SCC)	$18.60-$66.40	2004	37	In a recent working paper, Tol (2004) gathers 103 estimates from 28 published studies to form a probability density function. The mode is $2/t CO^2, the median $14/t CO_2 (18.59), the mean $93/t CO^2, and the 95 percentile $350/t CO_2. The conclusion was that the marginal damage costs of carbon dioxide emissions are unlikely to exceed $50/t CO_2 (66.38), under standard assumptions about discounting and aggregation, and probably much smaller.
	$10.40-$227.80	2004	37	In 1996, the IPCC Working Group III published a review on the first generation models. The range of SCC in the review is $5-$125/t CO_2 (in 1990 prices, or $6 - $ 160/t CO_2in 2000 prices). It was also estimated that this range was to increase to $7- $ 154/t CO_2 (10.39 – 227.8) (in 1990 prices, $ US?) for the period 2001-2010 (because the MD of carbon tends to increase with the level of atmospheric concentration of CO_2).
	$5.94 – 29.76 & 7.93 – 53.55	2003	37	Pearce (2003) reviews the studies which exhibit a range of SCC from the paper is £3-6 t/ CO_2 ($4.35-8.7/tC) without equity weighting, while equity weighting raises the range to £3-15t/ CO_2 (5.94 – 29.76). Time varying discount rate will raise the range further to £4-27 t/ CO_2 (7.93 – 53.55) ($5.8-39/tC).
	$177	2000	19	As such, a value of approximately £70t/ CO_2 (155.32) (2000 prices, with equity weighting), seems like a defensible illustrative value for carbon emissions in 2000. This figure should then be raised by £1 t/ CO_2 (2.21, so 2010 price is 177.43) for each subsequent year.
	$46.8	2002	79	Pratt, 2002, $40/t CO_2= damage cost (46.8).
WATER QUALITY				
Water Quality (Usability)	$246, $364, $67.15, $49.54	1993	10	Carson and Mitchell (1993) the WTP for increased water quality for all rivers in the US. They find that WTP per capita per annum is €118.5 (245.6) for water quality improvement from an unusable to a boatable level, and €175.6 (363.95) for further improvement to a swimmable level. The incremental value of improvement from boatable to fishable is €32.4 (67.15) and from fishable to swimmable, €23.9 (49.54).
Water Quality (Appearance)	$24.64	1999	11	On average, households would be willing to pay an extra A$18 (24.64) in water costs to improve the appearance of Canberra from `brown', the base case outcome, to `some brown'.
Water Quality (Property Premiums)	$27.6 – 162.84 & 144.9 – 211.14	1996	79	Michael *et al* (1996) found that 1m improvements in water clarity resulted in property premiums of 2 to 17%. WTP as a once off tax improved water quality in the Barwon-Darling River system, Sydney: $20-118 ($27.6 – $162.84) and Residents of the Darling River region $105 - 153 (144.9 – 211.14) per household (AU 1993 $).
	1 – 20%	2003	79	(HP) Washington State Department of Ecology (2003) found that property premiums associated with improvements in water quality range from 1 - 20%.
Water Quality (Faecal Coliform Level per m^3)	1.5%	2000	79	Leggett and Bockstael (2000) found that increases of 100 faecal coliform counts per 100mL in receiving waters resulted in 1.5% drop in adjacent property prices.
	$0.727		10	On average these studies place a value of €0.43per m3 (0.727) of clean water.
Water Quality (Bottled Water)	$61 – $630	1994	10	Abdalla (1994) annual costs for expenditure on bottled water to address organic contamination alone ranged from €27.3 (61.09) to €281.3 (629.51) per year.

Externality Type	$AUD (2010)	Year of Study	Reference source (see Appendix B for reference details)	Explanation/Comments
Water Quality (Suspended Solids)	$1.116 – 2.79	2002	10	Um *et al.* (2002) estimated improved drinking water quality in Pusan, Korea and find that marginal WTP estimation results for a small reduction, 10mgl−1 of suspended solid concentration in tap water from 335mgl−1 range from €0.60–1.50 (1.116 – 2.79) per month per household.
Water Quality (Thresholds and Standards)	$19.62 – 28.16		51	WTP for improvements in coastal water quality (Great Yarmouth and Lowestoft) up to current EU mandatory levels by residents was estimated to be £9.33 - £13.50/yr (19.62 – 28.16).
	$17.16 – 22.50 & 9.86 – 12.19		51	Residents in a South West Scotland town (Ayr) WTP for improvements to current EU water quality standards to be £9.22 - £12.13 (17.16 – 22.50) household/yr and £5.29 - £7.62 (9.86 – 14.19) household/yr.
Water Quality (per Trip)	$0.89, $10.81		51	Hypothetical water quality improvements lead 1.3% increases in trip frequency. Consumer surplus due to water quality improvements was estimated to be £0.48 (0.89) per trip or £5.81/person (10.81).
Water Quality (other)	67.24 – 1269.74		62	(Synthesis data) Value of water quality ranges from $35 – 661/yr (67.24 – 1269.74).
	202.87	1998	10	Yapping (1998) estimate the value of improving the water quality of East Lake in Wuhan. Total value of an improvement in water quality (202.87) for drinkable quality level.
	120.13, 58.13, 4.69	2004	10	Hensher *et al.* (2004) Australian consumers' WTP to avoid interruptions in water service and overflows of wastewater, WTP €71.7 (120.13) to reduce the frequency of interruptions when they face one interruption in ten years, while the average WTP is only €6.1 when customers face monthly interruptions. Consumers' WTP to reduce the length of water services interruptions ranges from €34.7 (58.13) for interruptions of 1h to €2.8 (4.69) for interruptions of 24h.
NUTRIENTS				
Nutrients NITROGEN Point source	$29,250 – $146,250 / tonne	2005	35	Industry (soda factory) $12,500-$125,000/tonne N (29250 – 146250).
	861		2	Average annual point source load reduction $820/tonne N (861).
	$63,000 – $7.4mill		28	Point Source Nutrient Abatement costs: nitrogen $60,000-$7million/tonne/year (63000-73500000).
Nutrients NITROGEN Diffuse Source	117000 - 936000		35	Industry (soda factory) - diffuse sources $10-$80,000/tonne (117000 – 936000).
	8980.5		3	Average annual cost of diffuse source load reduction $8,553/tonne N (8980.65).
	38850 – 53.6mill		28	Diffuse source nutrient abatement costs: nitrogen $37,000-$51m (38850 – 53550000).
Nutrients NITROGEN Treatment Costs	234000		35	Industry (soda factory) -WWTP $200,000/tonne (234000).
Nutrients NITROGEN (N) Current Charges	872		51	Developers are currently levied one-off offset charge of $800/kg (872) of nitrogen.
Nutrients PHOSPHORUS (P) Point Source	1073		3	Average annual point source load reduction $1,022/tonne P (1073).
	64050 – 11.6mill		28	Point Source Nutrient Abatement costs: phosphorus $61,000-$11m/tonne/year (64 050 – 11550000).
Nutrients PHOSPHORUS Diffuse Source	$41721.75 -		3	Average annual cost of diffuse source load reduction $39,735/tonne P (41721.75) (Alam, Rolfe and Donaghy, 2006, p. 12).

Externality Type	$AUD (2010)	Year of Study	Reference source (see Appendix B for reference details)	Explanation/Comments
	$21,000 – $191.1mill		28	Diffuse source nutrient abatement costs: phosphorus $20,000-$182m (21 000 – 191100000).
Nutrients PHOSPHORUS Reducing specific loads	$10.50, $14, $16.40, $19.90, $40.95, $11700 (?)		7	Cost of reducing phosphorus loads; Effluent management at dairies $9/kg/year (10.53); Runoff detention at market gardens $12/kg/year (14.04); Manage stock access at dairies $14/kg/year (16.39); Modified fertiliser use at market gardens $17/kg/year (19.89); Grassed drains, diversion banks & filter strips at market gardens $35/kg/year (40.95); Upgrading sewage treatment plants $10,000/kg/year (11700).
Waterway Health	$52 - $103; $72-$226; $152- 226		79	Farber and Griner (2000), Pennsylvania; WTP for waterway health, stream improvements from: 'moderately polluted to unpolluted = $26 - 51.35 (52.32 – 103.34); 'severely polluted' to 'moderately polluted' = $35.90 - 112.44 (72.24 – 226.29) ; from 'severely polluted' to 'unpolluted' = $75.63 - $112.44 (152.21 – 226.29)(per household, p.a., over 5 yrs, US 2000 $).
ECOSYSTEM				
Ecosystem – Improvement to Flows	$57.5,$30.4 /hh/yr		11	A$42 (57.54) annual increase in the household cost of water for an improvement in river flows from zero to some rivers, and from some to all rivers A$22 (30.4) .
Ecosystem - Wetlands	$622		10	They found that a decrease in the distance to the nearest wetland by 1,000ft (304.8m) from an initial distance of 1mile resulted in an increase in property value of €371.6. (622.58).
	$67/hh/yr		62	WTP $27/household/yr (67.12) (AU) to protect the Nadgee Nature Reserve (Aust.).
	$145 - $277		62	WTP $96 – 184/household/yr (144.67 – 277.27) to support a single program aimed at enhancing wetlands and habitat in San Joaquin Valley (US).
	$505-$ 6629		77	Marginal implicit price of reducing the distance to the nearest wetland by 1 metre, evaluated at the mean sales value, is AU $463 (504.67). If more than one wetland within 1.5km of property, second wetland increase property price by AU $6,081 (6,628.29).
	$339.8mill		77	For a 50ha wetland estimate total premium on sales due to wetland proximity is AU$220 mil (339.8 mil) (medium density and average property characteristics.
	$20,469 per day ; & $1.84 /hh		10	They find the value of the recharge function is €11104 per day (20468.93) for the wetlands and the average welfare change for a 1-m change in water levels is approximately €0.1perhousehold (1.84).
	$37,149 ; $24056 /ha/yr		79	Costanza *et al*, 1997, Ecosystem services of estuaries $22 832/ha/yr (37149.43), wetlands $14 785/ha/yr (24056.35) (1994 US $).
	7.53815 (trillion), 31129.04, 84650.32	1997	69	Wetlands provide a variety of services, which confer immense economic benefits to society. Their value has been estimated at $4.9 trillion/year (7.53815 trillion), globally (Costanza *et al.*, 1997). A review of wetland utilisation in Canada assigned a value of $20,769/acre (31129.04) to their functions in water purification and as pollution sinks, and $56,478/acre (84650.32) in regulating peak floods.
	$45.56	2006	61	Mean WTP for wetlands €27.20 person/yr (45.56) (in 2006 UK).
	$5.7bill	1981	9	Canada's wetland system has been valued in 1981 to be worth in excess of US3.9billion dollars (5.706792 billion).
	11.17 – 123.6		62	(Synthesis data) Value of non-use wetland habitat ranges from $8 – 96/per household/yr (11.17 – 123.60).
Ecosystem - Waterway Health	184.73 – 21.29	2002	79	Thomas *et al* 2002, WTP to avoid waterway degradation $0.35/km/household/yr (0.434) AND ACT residents WTP $133 – 155 (184.73 – 215.29) to improve health of creeks and rivers in the area (once off levy, 1998 $).
	0.107	2000-01	79	Van Bueren and Bennett (2000 and 2001) Nationwide WTP $0.08 p.a. (0.107) (yr 2000 $) per household as an env. levy over 20yrs to restore 10km of nearby waterways.
			23	WTP $0.30 per % of river estuary in good health and $3.40 per 1,000ha of healthy wetland.
	1.27 – 2.56		8	WTP for an increase of 1% in the length of river with healthy vegetation and wetlands, $1 – 2 per person (1.27 – 2.56).
	3.018	2006	61	Mean WTP for watercourses €1.80 (3.018) person/yr (in 2006 UK).

Externality Type	$AUD (2010)	Year of Study	Reference source (see Appendix B for reference details)	Explanation/Comments
Ecosystem – Beaches/Coastal Areas	15.17 – 24.74		62	WTP $9.26 – 15.1/household/yr (15.17 – 24.74) for the protection of beach ecosystems in New Jersey, US.
	12.6mill – 71.2mill		62	(Synthesis data) Value of non-use coastal habitat ranges from $9 – 51 M per household/yr (12570012 – 71230068).
	4121.88, 2693.97, 45.53, 46.43		49	Annual average WTP per household is (in relation to coastal ecosystems); $3,268 (4021.88) for aesthetic services; For land cover saltwater wetland, marsh or pond $2,189 (2693.97) per household; near shore island $37 (45.53); beaches $38 (46.43) per household per year.
Ecosystem - Fisheries	555.60		79	KPMG, 1998 WTO per recreational angler in Moreton Bay for the preservation of a fishery threatened by pollution may be around $400 p.a. (555.60).
Ecosystem - Habitat	32123364		62	(Synthesis data) Value of natural areas providing for habitat/recreation ranges from $23 million/yr (32123364) or $23/trip (32.12).
BIODIVERSITY				
Biodiversity - Fish	192.6m	1999	79	Layton *et al*. (1999), Washington, study, people would be WTP $127 million (192632070) (1998 US $) over 20yrs to increase fish populations by 0.2% to 0.5%.
	9.85	2001	79	Bennett and Morrison (2001), NSW, $7.70 (9.85) for presence of additional species of native fish in river (per NSW household 2001 $).
	4.40		76	WTP $4.40 per fish species.
	2.56 – 3.84		8	WTP $2 – 3 (2.56 – 3.84) for an additional fish species.
	0.42	2001	79	Whitten and Bennett (2001), $0.34 (0.42) per 1% increase in population of native fish along Murrumbidgee River (per household as one off payment).
	4.4		76	WTP $4.40 per fish species.
	2.56 – 3.84		8	WTP $2 – 3 (2.56 – 3.84) for an additional fish species.
	22.14 – 30.17	1997	15	WTP $14.38 – 21.40/household/yr (22.14 – 30.17) for the restoration of the Atlantic salmon into one river in Massachusetts (US1997).
Biodiversity - Waterbirds	4.26	2001	79	Bennett and Morrison (2001), NSW: $2.37 (4.26) for additional species of waterbird other fauna species ($ per NSW household 2001 $).
	0.70	2001	79	Whitten and Bennett (2001), value of floodplain wetlands along Murrumbidgee River, respondents in region WTP $0.55 (0.70) for 1% increase in native wetland and woodland birds (per household as one off payment).
	1.279 – 2.56		8	WTP $1 – 2 (1.279 – 2.56) for an additional for waterbird and other fauna species.
	6.7		76	WTP $6.70 per 1 % increase in native birds or per breeding pair.
	80.55 – 96.66		62	WTP $50 – 60 (per ha)/household/yr (80.55 – 96.66) for the conservation of waterfowl in Canada's wetlands.
	88.2 – 106.14		62	WTP $59 – 71/household/yr (US) (88.2 – 106.14) for the conservation of the migratory waterfowl in the Central Flyway (US).
	6.85, 32.86		11	WTP to prevent losses in habitat for uncommon species is approximately A$5 per species (6.85), or A$24 (32.86) for five species.
Biodiversity – Endangered Species (unspecified)	5.7, 5.87	1997	8	WTP between $4.04 (5.70) and 4.16 (5.87) (A1997) for an additional endangered species to be preserved in wetlands.
	30.7, 6.4	2001	36	WTP $24 (30.7) (increase in household water prices) to reduce habitat loss for 5 species, or $5 (6.4) per uncommon species ($Au, 2001).
	16756		62	WTP $118 (167.56) (Au)/household/yr for preservation of all endangered species in Victoria.
	204.16	2006	61	Mean WTP for endangered species protection €120.90 person/yr (204.16) (in 2006 UK).
Biodiversity – Single Species	6.98 – 175.98		62	(Synthesis data) Value of a single species ranges from $5 – 126/per household/yr (6.98 – 175.98).

Externality Type	$AUD (2010)	Year of Study	Reference source (see Appendix B for reference details)	Explanation/Comments
	41.18		62	WTP for the conservation to Leadbeaters possum (Australia) $29/household/yr (41.18) ($Au).
Biodiversity – Genetic Diversity			62	(Synthesis data) Value of genetic and species diversity (through bio-prospecting) from $175 – 3.2 million annually (244 416 900 – 4 469 337).
	1.7mill		62	INBio and Merck (1991), payed $1 million (1 736 280) for the right to study 2000 samples of Costa Rica genetic pool.
Biodiversity	27.28 – 124.92	1999	10	Morrison *et al.* (1999) to estimate the non-use values of environmental, as well as social and economic attributes of the Macquarie Marshes wetland in Australia. They find that the Australian public is WTP substantial amounts (€13.3 to €60.9per household (27.28 – 124.92) depending on the model and management scenario employed) in order to increase the wetland area, to improve the biodiversity found in the wetland, and to increase irrigation related employment.
	48.39	2006	61	Mean WTP for biodiversity preservation €28.66 person/yr (48.39) (in 2006 UK).
Biodiversity – Wildlife Preservation	3.04	2006	61	Mean WTP for wildlife preservation €1.80 person/yr (3.04) (in 2006 UK).
Biodiversity – Native Vegetation	$3.10		76	WTP $3.10 per % of river or river length covered with healthy native vegetation.
2. Socioeconomic Costs and Benefits				
PRODUCTION				
Production - Commercial Fishing	$46.8mill	2002	79	Taylor (2002), value of commercial fishing in Moreton Bay $40M p.a. (46800000).
	$3mill - $61.5mill	1997	79	US EPA (1997), stormwater runoff costs US commercial fish and shellfish industry approx. $17-35mill p.a. (29862495 – 61503273) (US $).
RECREATION				
Recreation - Beaches	$65.68	1990	10	Bell and Leeworthy (1990) investigate the tourists' recreational demand for saltwater beach days in Florida and find the daily consumer valuation to be nearly €29 (65.68).
Recreation - Rivers	$29.38	1990	79	Walpole (1990), WRP average $23.69 (29.38) per household per visit for recreation at river sites in northern Victoria (2002, AU$).
	$73.67, 55.06	1991	79	Sanders *et al* (1991) recreational value of rivers in Colorado, $59.41 (73.67) (CV) and $56.05 (55.06) (TCM) per visitor per day (Estimates are conservative as used local residents only).
	39.13	1990	79	Siden (1990) recreational value of rivers, northern Victoria. WTP $31.56 (39.13) for recreational opportunities per household p.a. (Conservative est) (2002 AU$).
	229.4	1993	79	ABS (1993) QLD residents spend on average $185 (229.4) on recreational fishing annually AND value of Brisbane River and Moreton Bay region recreational fishing industry is $200M p.a. (2002 AU$).
Recreation - Fishing	3.7mill, 12.0mill, 3.6bill	2002	79	Taylor (2002), value of freshwater recreation fishing industry in Brisbane region to be approx. $3M p.a. (3720000) and in the wider Moreton Bay to be $9.7M p.a. (12028000) and McIlgorm and Pepperell, 1999 estimate national expenditure in Australia to be $2.9B p.a. (3.5966B) (2002 AU$).
	58.15		76	WTP $51.60 (58.15) per water quality increase to be fishable/swimmable.
Recreation - Boating	44.58mill	1998	10	Yapping (1998) in China to estimate the value of improving the water quality of East Lake in Wuhan. Total value of an improvement in water quality to boatable level is estimated at €21.4million (44.58M).
Recreation - Swimming	114.17mill	1998	10	Yapping (1998) in China to estimate the value of improving the water quality of East Lake in Wuhan. Total value of an improvement is as high as €54.8million (114.17M) for swimmable quality level.
	58.15		76	WTP $51.60 (58.15) per water quality increase to be fishable/swimmable.

Externality Type	$AUD (2010)	Year of Study	Reference source (see Appendix B for reference details)	Explanation/Comments
Recreation - Other	$31.25	1991	79	Green and Tunstall (1991), (162) WTP for water quality improvements to enable recreation related 'use' values in England. WTP approximately $44.74 p.a. (44.74) (2002 AU $) as increase to water rates (Note if zero estimates included drops to $27.73 (31.25).
AMENITY				
Amenity – Property Premiums – Water Frontage	28%	1991	79	US Department of Housing and Urban Development, (1991), all else being equal, the price of a house located within 300m of any body of water (e.g. beach, pond, lake etc) value of house raises by up to 28%.
	80%	2001	79	Campbell (2001), study of Forest Lake in Brisbane found: Residential housing with open water frontage attracts a 80% premium; Lots with immediate access to a park with landscaped and constructed drainage channel/waterway attract a premium of 25%; Lots with immediate access to creek 10% premium.
	17%	2001	79	Lloyd (2001), Properties with frontage onto a constructed wetland in Melbourne attracted a 17% higher price than average block price.
	3 – 13%	1995-96	79	Streiner and Loomis (1995 and 1996) reported that homes near restored streams had 3 - 13% higher prices than similar homes on unrestored streams.
Amenity – WTP for Waterway Restoration	1.193	2001	79	Van Bueren and Bennett (2001), Australians WTP on average $0.07 (1.193) p.a. per household as an environmental levy over 20yrs to restore 10,000ha of land for aesthetic reasons (2000 AU$).
	0.46	2002	79	Robinson *et al.* (2002), residents of Bremer River in SEQ WTP $0.37 (0.46) per person p.a. (2002 AU $) to increase total length of the river with a 'very good' appearance by 1%.
NON-USE				
Non-use Values – Rivers	$44.73, 79, 103.31	1990	79	Sanders *et al.* (1990), WTP for protection of rivers in Colarado: Option Value: $15.67 (44.73), Existence Value: $27.67 (79.00) and Bequest Value $36.19 (103.31) (per household, p.a. in US 1983 $).
	$16.26, 16.05		47	Values associated with the Rakaia River (NZ): health of in-stream river flows Option Price: $17.60 (16.26) and the Preservation Price: $17.38 (16.05) (NZ $ per household, p.a.).
Non-use Values	$12.79	2001	36	WTP $10 (12.79) (increase in household water prices) for a 10% reduction in household water use ($AU, 2001).
	$60.11, -$70.35	2001	36	WTP $47 (60.11) (increase in household water prices) for the provision of recycled water for outdoor use. However WTP -$55 (70.35) for recycled water for all uses (as many are unwilling to drink recycled water) ($AU, 2001).
	116.18, 179.55, 174.27	1982	79	Greenley *et al.* (1982), WTP preserve quality of receiving waters in the US, Option Value: $93.69 (116.18), Existence Value: $144.80 (179.55), Bequest Value: $140.54 (174.27)(Per household, p.a. in AU 2002 $).
HEALTH				
Health	5.17mill	1990	81	Wage differential studies in the US indicated that the value of a statistical life (VSL) is approximately $US 5 mill (1990).
	596 909	1999	81	VSL in Mexico City was approximately $300 000 (US$, 1999).
	345		26	US $300 for a 0.0001% reduction in the risk of premature death.
	488.52	1992	26	Cost of Illness: US $ 258 (1992) for an average emergency room visit.
	109.82	1992	26	Cost of Illness: each restricted activity day due to illness is worth on average $58 (US, 1992).
OTHER				
Other	−52 to +58%		76	WTP estimates ranging from −52 to +58% of the average property price associated with a risk exposure of 0.01 per year.

4.4. Some Exploratory Additional Externality Valuations

As an example of the incorporation of externality values in the full social cost accounting of future scenarios in water management planning, a preliminary analysis of GHG emission effects is considered in this Section. The analysis is simplistic and meant for demonstration purposes only. The valuation of the external impacts of GHG emissions associated with the management scenarios is assumed to be $23 per tonne – in line with the initial working price (implied cost) for a tonne of carbon for Australia's current Clean Energy Plan. Of course, there is a great deal of uncertainty relating to the potential effects of GHG emissions and valuations vary widely (see Table 13). Estimates range from less than $20 per tonne to over $300 per tonne in the Stern Review on the Economics of Climate Change. The emissions are calculated over 20 years and no discount rate is applied as carbon prices are likely to maintain their current real values into the future.

In Figure 4, a tentative assessment shows that the $23/tonne valuation for GHG emission externalities does not have a major impact in relation to the net present value (NPV) of the capital and operating costs associated with each scenario (and their component solution sets).

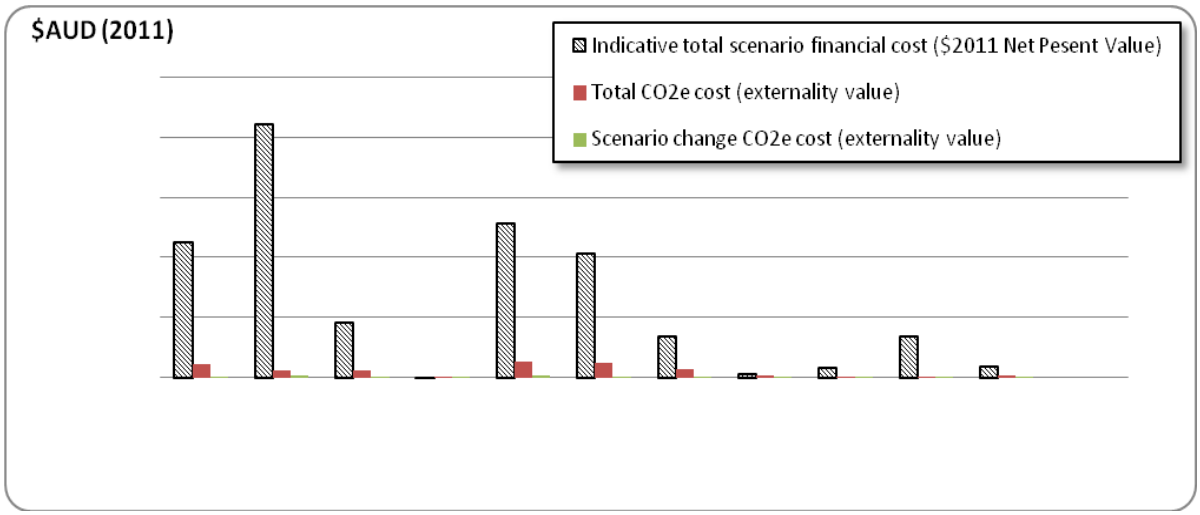
The externality costs of GHG emissions are rarely more than 2% of the total indicative financial costs to implement the proposed management scenarios.

The valuations of total CO_2 emissions associated with the management scenarios are more significant and can be equal to up to 82% of the indicative NPV costs (for example, for Brisbane Coastal Scenario 1) but are more often around 10-20% with many below 5%.

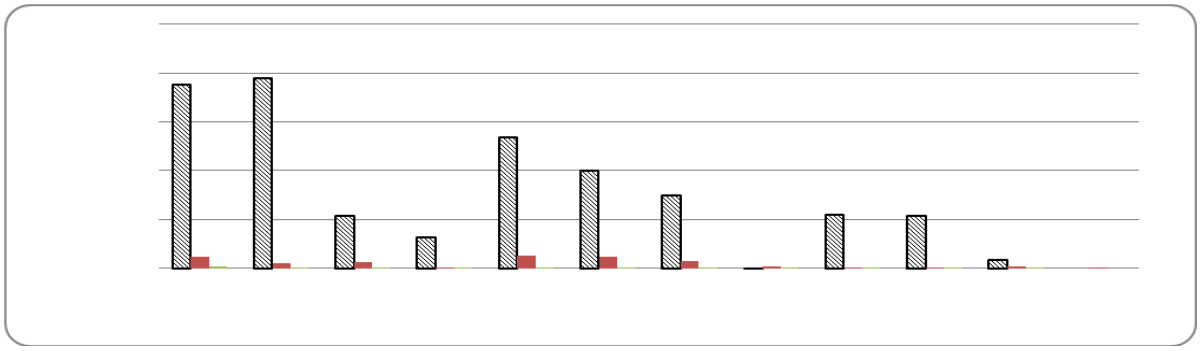
With appropriate biophysical and quantitative data for the other potential externalities identified in this report, it would be possible to analysis an extensive range of TBL impacts to assess the relative magnitude or trade-offs in welfare associated with these effects. While some economic valuation estimates per unit of externality impact are provided in Table 13, more specialised assessment of their local geographical, technical and operational characteristics is necessary within the catchment and management scenarios.

Figure 4: **Total Financial Costs in Relation to Greenhouse Gas Emissions Externality Valuations.** By scenario and MBRC catchment.

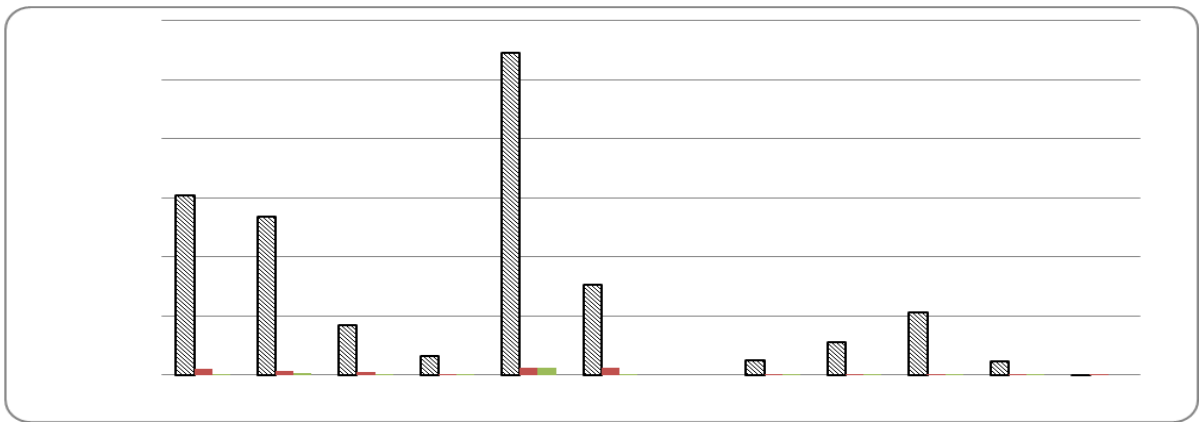
SCENARIO 1:



SCENARIO 2



SCENARIO 3



5. CONCLUSION

This report provides a wide-ranging, if preliminary, analysis of the social, economic and environmental externalities associated with water recycling, stormwater harvesting and rainwater tanks under a total water cycle management (TWCM) planning approach for the Moreton Bay Regional Council (MBRC) in South East Queensland (SEQ).

In other sections of this UWSRA project, water quality measures of total suspended solids, nitrogen and phosphorus, and greenhouse gas (GHG) emissions have been included under an extended cost-effectiveness framework for the study area (Hall, 2012). However, there are many other relevant external impacts and they should be considered for true TBL accounting and assessment of water servicing solution sets. There are a wide range of externalities associated with these options and valuation information reflecting social costs and benefits, and hence trade-offs to the community. Estimation of these costs and benefits may have a significant effect on the preferred rankings and community evaluation of regional solution sets.

Decision-making directed towards sustainable resource management and triple bottom line (TBL) accounting requires the identification and incorporation (and ideally some idea of values or trade-offs) of the full range of private and external effects associated with major strategic options. Well-being effects of human actions are not taken into account directly in market-place transactions are known as "externalities". However, externalities have very real and significant impacts of community well-being and hence the efficiency, effectiveness and desirability of alternative options for resource use in society. Externalities can no longer be treated as extraneous to water resource planning (Davis, 2006).

The primary aim of this report has been to develop a method guide and provide indicative supporting data for the identification, valuation and incorporation of externalities for water servicing options. This capability is essential for the more complete TBL accounting and decision-making processes that will increasingly become the standard in project assessment. Although the report is specifically targeted at providing the initial scoping information for the MBRC, the case study approach is intended to inform the extended application of externality analysis and TBL accounting to any related water servicing planning context.

The report does not comprise a complete extended externality analysis of TWCM water servicing options considered for the MBRC. The generation of the biophysical and other social and economic quantitative externality data required for economic valuation of additional effects (to the nutrient, energy and GHG emission impacts covered in other related studies) has been beyond the resources of this small project. The purview of the report has been limited to: (1) scoping for the full range of externalities that are likely to relevant in the study setting; (2) the review and compilation of existing quantitative and valuation estimates of these externalities in other studies; and (3) discussion of initial context-relevant considerations, in order to proceed with a complete externality of TBL accounting analysis in the case study setting.

The process of the initial measurement of biophysical and other social and economic quantitative externality data required for assessing their significance and economic value is a major area recommended for additional R&D. The identification of relevant potential externalities and their indicative economic values is demonstrated in this report. However, the next essential step is to investigate a cost-effective and systematic process for providing context-specific data. Comprehensive TBL accounting with the full analysis of significant social, economic and environmental impacts (or constraints) will be the norm in project assessment within a decade. Many lessons have been learnt to date and increasing social, corporate and environmental accountability, and growing energy and other resource vulnerability will reinforce this trend.

The report presents the results of a detailed survey and review of the externalities associated with a sample of water servicing options that are being considered for application within the TWCM planning for MBRC area. The TWCM planning process does not currently incorporate externality

analysis in the assessment and decision-making process. The TWCM process would benefit from the incorporation of the externalities identified and valuated throughout this report.

The first major data set presented is a systematic tabular summary of all significant externalities associated with the non-potable water recycling, stormwater harvesting and rainwater tanks. It includes details on the nature of each externality – for example, whether it is typically a positive or negative impact; whether it occurs in upstream, downstream or local locations; and the type of externality impact (e.g. "GHG emissions", "nutrient", "recreation", or "ecosystem"). The externality types have been selected on the basis of identified relevance, focus and application in existing research on water-related externalities. The externality identification list and description is also classified into the relevant life cycle or operational phase of the option and a more "general" component cutting across these phases. Chapter 3 provides some detailed description of the technical nature and impacts of each option under study.

In the second major data set, the results for the extensive survey of existing economic valuation for relevant externalities are compiled and presented. This includes specific information on reference sources, together with notes about the relevant valuation context (e.g. the location and study focus). The individual effects have been allocated to their (most) appropriate externality category as described in Chapter 2. Each of the valuations has been converted to $AUD 2010 based on historical exchange rates and Gross Domestic Product (GDP) implicit price deflators. Commentary on the caveats for specific externality and group valuations, and gaps in data availability and coverage, are also included in this section.

As noted, the purpose of this report is to provide externality analysis for three water servicing options proposed in for use in TWCM in the MBRC area. However, the externality "checklists" and indicative economic value estimates will be of widespread use to practitioners concerned with sustainable water management (and, indeed, for strategic resource management purposes in general). The information can be used in many ways including the sourcing of estimates for social cost-benefit analysis and other decision-making or policy formation processes where a full range of externalities are considered (and are interested in at least provisional indications of existing economic magnitudes). Hence, this report provides water managers, scientists, and practitioners involved in TWCM planning in SEQ (and further abroad) with a detailed reference to help incorporate the full range of costs and benefits into their option and scenario assessment and decision-making.

Improved identification and information about the likely external effects of alternative water options and the magnitude of their economic impacts can assist in the efficient allocation of resources and avoid unexpected costs later in the project cycle (Siebert, Young and Young, 2000). It is important to incorporate both private (direct market) and external costs and benefits in water-related decision making activities, as their neglect can encourage investment in sub-optimal alternatives which may prove regrettable in the long-run (Bryan and Kandulu, 2009). Without a consideration of externalities, decisions tend to made on the basis of a combination of financial analyses and political lobbying, drawing upon partial and typically biased assessments.

Financial analysis includes only direct market-based costs and benefits – such as the construction, operation and treatment costs of supplying water from a new dam. Externality analysis provides a more systematic and comprehensive inputs to guide decision-making by identifying, quantifying and assessing the relative trade-off values that might be associated with the full range of long-term costs and benefits of proposed water options. This fits into the stated principles of TWCM planning.

This research supplements the TWCM planning processes and decision-making methodologies. The externality analysis methodology allows a more comprehensive economic assessment of the potential water servicing options. It can also assist in identifying indirect social and environmental impacts which may have been overlooked or deemed as insignificant throughout previous planning stages. However, it must be acknowledged that empirical data and research in the area is limited and direct application to the SEQ context is constrained by a dearth of local studies.

APPENDIX A: A Summary of Studies of Health Risks associated with Rainwater Tank Use

Region of Study	Year	Author	Cited in	Description of Study and Results
Rural NSW	2000	Goodall	Goodall, 2000, p 124 - 126	"The aim of this investigation was to ascertain whether untreated water drawn from rivers, springs and rainwater tanks, and which is intended for drinking purposes in rural accommodation establishments, complied with the Australian Drinking Water Guidelines…. All four water samples taken from treated supply sources met the bacteriological standards for drinking water as recommended by the Australian Drinking Water Guidelines. Of the remaining 11 samples taken from untreated supplies, only three samples met the bacteriological standard of the guidelines. Therefore, 73 per cent of the raw water supplies failed to meet the bacteriological standards for drinking water."
Auckland, NZ	2001	Simmons *et al*.	Lye, 2009, p.5432	"Investigated for chemical and microbiological contaminants one-hundred and twenty-five domestic rooftop rainwater systems in four rural Auckland districts. Their studies suggested that rooftop rainwater was of relatively poor quality. Potential microbial pathogens such as Salmonella, Aeromonas and Cryptosporidium were identified in some of the rooftop-collected rainwater. The survey also suggested a significant association between the presence of Aeromonas and increased gastroenteric symptoms among household users."
Denmark	2002	Albrechtse n	Lye 2009, p.5432	"Different collection surfaces were found to influence the microbial populations that were detected. Since no disinfection residual was present in Danish drinking water networks, their study suggested that improperly designed rainwater systems could increase risks of infection to household water supplies especially if cross contamination were to occur."
Worldwide	2002	Lye	Lye 2009, p.5432	"Lye reviewed the common occurrence of various pathogenic microorganisms reported in scientific studies sampling rainwater systems worldwide (Lye 2002). The microbial risks associated with rainwater from rooftop collection could be attributed to diseases ranging from bacterial diarrhoea and bacterial pneumonia to tissue helminth infestations when untreated rainwater was consumed."
Tasmania, Australia	2006	Ashbolt and Kirk	Lye 2009, p.5432	"A case–control study in Tasmania that single variable associations were found between drinking untreated rainwater and cases of infection with Salmonella Mississippi. Interestingly, the highest risk was associated with exposure to untreated rainwater away from the home of the participants. These higher risk estimates probably reflected a lower level of immunity in populations not frequently exposed to the pathogen. Direct contact with native animals known to be a source of salmonellosis was not the cause of infections."
Mount Barker, Western Australia	2006	Tan *et al*.	Tam *et al*. 2006, p.53	"The aim of the study was to assess to what extent Cryptosporidium, Giardia, Campylobacter and Salmonella spp, in particular those that cause illness in humans, are present in rainwater tanks in rural Western Australia. None of the samples tested positive for Cryptosporidium, Giardia, Campylobacter, or Salmonella spp. However, thermotolerant coliforms were detected in three tanks and E.coli in two tanks. The study shows that rainwater tanks sampled were free from Cryptosporidium, Giardia, Campylobacter, and Salmonella spp. The absence of these pathogens might indicate that either animals present in Mount Barker were not reservoirs for these pathogens or that the current rainwater systems and maintenance were adequate in preventing contamination. The absence might also be a result of lower temperatures and higher water volume in winter months. "
South Australia	2006	Heyworth *et al*	Heyworth *et al*,, 2006, p	"Young children, who were regular consumers of tank rainwater, were at no greater odds of gastroenteritis than those who drank treated public mains water."
Auckland, NZ	2008	Simmons *et al*.	Lye 2009, p.5432	"An outbreak of Legionnaires Disease was reported in an isolated suburb of Auckland, Australia (Simmons *et al*. 2008). Using molecular-based technology they showed that the isolates of Legionella pneumophila from patient clinical specimens were identical to the high levels of L. pneumophila present in the nozzle of a local marina water blaster used to clean boats. Sampling of nearby rainwater collection systems revealed that contaminated water spray from the water blaster had been carried and deposited on roof surfaces in the local area. The L. pneumophila within the spray were washed into rainwater storage tanks and users were exposed through bathroom showers."
Brisbane, Australia	2009	Huston	Huston 2009, p.1638	"To characterise atmospheric input of chemical contaminants to urban rainwater tanks, bulk depositions (wet / dry deposition) were collected at sixteen sites in Brisbane, Australia on a monthly basis during April 2007–March 2008 (N ¼ 175). Water from rainwater tanks (22 sites, 26 tanks) was also

Region of Study	Year	Author	Cited in	Description of Study and Results
				sampled concurrently (Huston 2009, p.1630). There is an indication that deposition from the atmosphere is not the major contributor to high lead concentrations in urban rainwater tanks in a city with reasonable air quality, though it is still a significant portion… The study demonstrates atmospheric deposition does contribute to contaminants in rainwater in an urban environment. It shows that there is an increase in the contaminant flux in traffic/industrial areas compared to outer suburbs with marker elements implicating traffic as a major contributor. Rainwater collected in urban areas where air pollution is significant must consider the impact of pollution on the water quality."
Victoria, Australia (rural)	2009	Franklin et. al	Franklin et al. 2009, p.434	"In March 2007, an outbreak of gastroenteritis was identified at a school camp in rural Victoria, Australia, affecting about half of a group of 55 students. Environmental and epidemiological investigations suggested rainwater collection tanks contaminated with DT9 as being the cause of the outbreak. Increased use of rainwater tanks may heighten the risk of waterborne disease outbreaks unless appropriate preventative measures are undertaken. "
Gangneung, South Korea	2010	Lee *et al*.	Lee *et al*. 2010, p.896	"In this study, all of the harvested rainwater samples met the requirements for grey water but not for drinking water… Consistent with other studies, it shows that hygiene and maintenance practices may improve the quality of harvested rainwater. For example, the addition of first flush filters and diverters is one of the best ways we can keep systems clean and safe."

APPENDIX B: Externality Effects and Valuation References

Reference Number	Reference Details
1	Adams, P.D. (2007) Insurance against Catastrophic Climate Change: How Much Will an Emissions Trading Scheme Cost Australia? *Australian Economic Review* 40(4): 432-452.
2	Alam, K., Rolfe, J., and Donaghy, P. (2008) Assessing the cost-effectiveness of water quality interventions in SEQ. *Australian Journal of Environmental Management* (15): 30-40.
3	Alam, K., Rolfe, J., and Donaghy, P. (2006) Economic and social impact assessment of water quality improvement. *Australasian Journal of Regional Studies* 12(1): 85-102.
4	Angelakis, A., Bontoux, L., and Lazarova, V. (2003) Challenges and prospectives for water recycling and reuse in EU countries. *Water Science and Technology: Water Supply* 3(4): 59-68.
5	Asano, T. (2001) Water from (waste)water- the dependable water resource, *In 11th Stockholm Water Symposium*. Stockholm, Sweden.
6	Australian Government (2008) Carbon Pollution Reduction Scheme: Australia's Low Pollution Future. White Paper.
7	BDA Group (2005) Recent experiences in nutrient trading in Australia & internationally. Presented at New Horizons in Market-based Instruments Symposium.
8	Bennett, J. and Morrison, M. (2001) Valuing the Environmental Attributes of NSW Rivers - Final Draft. Environmental and Resource Economics.
9	Bergkamp, G., McCartney, M., Dugan, P., McNeely, J., and Acreman, M. (2000) *Dams, Ecosystem Functions and Environmental Restoration*. Prepared for the World Commission on Dams (WCD), Environmental Issues II.1.
10	Birol, E., Karousakis, K., and Koundouri, P. (2006) Using economic valuation techniques to inform water resources management: A survey & critical appraisal of available techniques and an application. *Science of the Total Environment* (365): 105-122.
11	Blamey, R., Gordon, J., and Chapman, R. (1999) Choice modelling: assessing the environmental values of water supply options. *The Australian Journal of Agricultural and Resource Economics* 43(3): 337-357.
12	Brennan, L., Lisson, S., Khan, S., Carberry, P., and Bristow, K. (2003) *An economic and environmental evaluation of the benefits and risks of recycled-water irrigated crop production on the Darling Downs*. CSIRO, Indooroopilly, Qld. Accessed 23 April, 2010. http://www.csiro.au/resources/CSE-publications-archive.html
13	Brown, C. (2009) Recycled Water: Risks, benefits, economics and regulation by system scale. *Recycling of Water: New Zealand Land Treatment Collective Conference*, Taupo, New Zealand.
14	Brown, R. (2005) Impediments to Integrated Urban Stormwater Management: The Need for Institutional Reform. *Environmental Management* 36(3): 455-468.
15	Brown, B. and Milne, C. (2010) The Greens Interim Carbon Price: Proposal for a transitional carbon pricing mechanism.
16	Byard, R. (2008) Rainwater tank drowning. *Journal of Forensic and Legal Medicine* (15): 533-534.
17	Centre for Sustainable Technology at the University of Newcastle (2010) *Blue Scope Steel 2010: Rain Water Tanks - Life Cycle Analysis*. Accessed 23 November, 2009. http://www.bluescopesteel.com.au/go/building-products/rainwater-harvesting/life-cycle-analysis-for-rainwater-tanks/rain-water-tanks-life-cycle-analysis/objectID/B303F6BA-88F6-475D-AEE714D5A6DE2644
17a	Byström, O. (1998) The nitrogen abatement cost in wetlands. *Ecological Economics* 26, pp.321-331
18	Ceronsky, M., Anthoff, D., Hepburn, C., and Tol, R. (2005) Checking the price tag on catastrophe: The social cost of carbon under non-linear climate response.
19	Clarkson, R. and Deyes, K. (2002) Estimating the Social Cost of Carbon Emissions. HM Treasury DEFRA (Department of Environment, Food and Rural Affairs).
20	Clouston, B. (2007) *Nutrient Offsets Scheme to Improve Water Quality in Moreton Bay - Stage 2: Progress Report 2*. Queensland Environmental Protection Authority.
21	Cohen, R., Wolff, G., and Nelson, B. (2004) *Energy Down the Drain - The Hidden Costs of California's Water Supply*. Natural Resources Defence Council and The Pacific Institute, California.
22	Coombes, P.J., Kuczera, G., Kalma, J.D., and Argue, J.R. (2002) An evaluation of the benefits of source control measures at the regional scale. *Urban Water* (4): 307-320.
23	Daniel, V.E., Florax, R.J.G.M., and Rietveld, P. (2009) Flooding risk and housing values: An economic assessment of environmental hazard. *Ecological Economics* (69) 355-365.
23a	Davis, C. K. (2006) *Ethical Dilemmas in Water Recycling*. Water Supply and treatment Division, San Francisco Public Utilities Commission, San Francisco, USA.
24	Dimitriadis, Dr. S. (2005) *Issues encountered in advancing Australia's water recycling schemes.* Information analysis and advice for the Parliament Research Brief. Parliament of Australia. Department of Parliamentary Services Parliamentary Library, Report no. 2, 2005 - 06.
25	Diesendorf, M. (2007) Greenhouse Solutions with Sustainable Energy. A Submission to Garnaut Climate Change Review.
26	Dixon, J.A. (1998) The Economic Valuation of Health. The World Bank.
27	Environment Australia (2002) *Introduction to Urban Stormwater Management in Australia*. Department of the Environment and Heritage, Commonwealth of Australia, Canberra. Accessed 12 May, 2010. http://www.environment.gov.au/coasts/publications/stormwater/pubs/stormwater.pdf.
28	Environmental Protection Agency (2008) Moreton Bay Water Quality Off-set Scheme Final Report. Queensland Government, Brisbane.

Reference Number	Reference Details
29	Environmental Protection and Heritage Council (2007) *Australian Guidelines for water recycling: Managing Health and Environmental risks (Phase 2) augmentation of drinking water supplies. NRM National Water Quality Management Strategy*.
30	Evans, C.A., Coombes, P.J., and Dunstan, R.H. (2006) Wind, rain and bacteria: The effect of weather on the microbial composition of roof-harvested rainwater. *Water Research* (40): 37-44.
31	Fletcher, T.D., Mitchell, V.G., Deletic, A., Ladson, T.R., and Se´ven, A. (2007) Is stormwater harvesting beneficial to urban waterway environmental flows? *Water Science and Technology* 55(4): 265-272.
32	Franklin, L., Fielding, J., Gregory, J., Gullan, L., Lightfoot, D., and Poznanski, S. (2009) An outbreak of Salmonella Typhimurium 9 at a school camp linked to contamination of rainwater tanks. *Epidemiology and Infection* (137): 434-440.
33	Furumai, H. (2008) Rainwater and reclaimed wastewater for sustainable urban water use. *Physics and Chemistry of the Earth* (33): 340-346.
34	Garnaut, R. (2008) The Garnaut Climate Change Review: Final Report. Cambridge University Press.
35	Gaylard, S. (2005) A tradeable rights instrument to reduce nutrient pollution in the Port Waterways: feasibility study. Environmental Protection Authority, Govt. of South Australia. http://www.epa.sa.gov.au/xstd_files/Water/Report/pw_rights.pdf
36	Gordon, J., Chapman, R., and Blamey, R. (2001) 'Assessing the Options for the Canberra Water Supply: an Application of Choice Modelling' in *The Choice Modelling Approach to Environmental Valuation*, Edward Elgar Publishing Ltd, Cheltenham, UK.
37	Guo, J. (2004) Discounting and the Social Cost of Carbon. MSc Thesis for Environmental Change and Management. University of Oxford.
38	Hallmann, M., Grant, T., and Alsop, N. (2003) *Yarra Valley Water Life Cycle Assessment and Life Cycle Costing of Water Tanks as a Supplement to Mains Water Supply*. Centre for Design at RMIT University, Melbourne.
39	Hanley, N., Bell, D., and Alvarez-Farzio, B. (2003) Valuing the Benefits of Coastal Water Quality Improvements Using Contingent and Real Behaviour. *Environmental and Resource Economics* (24): 273-285.
40	Hatt, B., Deletic, A., and Fletcher, T. (2004) *Integrated Stormwater treatment and re-use systems - Inventory of Australian practice*. Cooperative Research Centre for Catchment Hydrology, Technical Report 04/1.
41	Hatt, B., Deletic, A., and Fletcher, T. (2006) Integrated treatment and recycling of stormwater: a review of Australian practice. *Journal of Environmental Management* (79): 102-113.
42	Helmreich, B. and Horn, H. (2009) Opportunities in rainwater harvesting. *Desalination* 248(1 - 3): 118-124.
43	Hope, C. and Maul, P. (1996) Valuing the Impact of CO_2 Emissions. *Energy Policy* 24(3): 211-219.
44	Huston, R., Chan, Y.C., Gardnet, T., Shaw, G., and Chapman, H. (2009) Characterisation of atmospheric deposition as a source of contaminants in urban rainwater tanks. *Water Research* (43): 1630-1640.
45	Johengen, T. and LaRock, P. (1993) Quantifying nutrient removal processes within a constructed wetland designed to treat urban stormwater runoff. *Ecological Engineering* (2): 347-366.
46	Jordan, J. (no date) *Externalities and Integrated Resource Planning*. Unpublished paper. Accessed March 30, 2010. http://www.ucowr.siu.edu/updates/pdf/V104_A6.pdf
47	Kerr, S., Lock, K., and Kennedy, M. (2008) Cost sharing and allowance allocation in a nutrient trading system for the Lake Rotorua catchment. DRAFT document.
48	Lawson, K., Burns, K., Low, K., Heyhoe, E., and Ahammad, H. (2008) Analysing the economic potential of forestry for carbon sequestration under alternative carbon price paths. ABARE, Canberra.
49	Liu, S. and Stern, D. (2008) A Meta-Analysis of Contingent Valuation Studies in Coastal and Near-Shore Marine Ecosystems. CSIRO.
50	Marks, J., Martin, B., and Zadoroznyj, M. (2008) How Australians order acceptance of recycled water: National baseline data. *Journal of Sociology* 44(1): 83-99.
51	Marsden-Jacob Associates (2007) *The cost-effectiveness of rainwater tanks in urban Australia*.
52	Marsden Jacob Associates (2007) *The economics of rainwater tanks and alternative water supply options*. Camberwell, Victoria.
53	Miller, E. and Buys, L. (2008) Water-Recycling in SEQ, Australia: What do Men and Women Think. *Rural Society* 18(3): 220-229.
54	Mikkelsen, P.S., Vezzaro, L. Birch, H., Eriksson, E., Lützhøft, H., Høg, H. and Sharma, A.K. (2012) Monitoring, chemical fate modelling and uncertainty assessment in combination: a tool for evaluating emission control scenarios for micropollutants in stormwater systems. Paper presented at the 7th International Conference on Water Sensitive Urban Design 21–23 February 2012. Melbourne Cricket Ground, Melbourne, Australia.
55	Mitchell, C. and Rahman, A. (2007) Rainwater Tanks: Costs and Benefits. *Issues* 79 (June): 41-42.
56	Mitchell, V., Deletic, A., Fletcher, T., Hatt, B., and Mcarthy, D. (2007) Achieving multiple benefits from stormwater harvesting. *Water Science and Technology* 55(4): 135-144.
57	Mitchell, V. G., Hatt, B. E., Deletic, A., Fletcher, T. D., McCarthy, D. T., and Magyar, M. (2006) *Integrated Stormwater Treatment and Harvesting*: Technical Guidance Report. Institute for Sustainable Water Resources (ISWR) Report 06/05, Monash University, Melbourne. Accessed 14 December, 2009. http://iswr.eng.monash.edu.au/research/projects/stormwater.
58	Naji, F. and Lustig, T. (2006) On-site water recycling - a total water cycle management approach, in *International Conference on Integrated Concepts on Water Recycling*.

Reference Number	Reference Details
59	Nanbakhsh, H. (2005) Design Compasison of Experimental Stormwater Detention Systems in Treating Concentrated Road Runoff. *Iranian Journal of Environmental Health, Science and Engineering* 2(3): 169-176.
60	Nancarrow, B. E., Kaercher , J. D., Po, M., and Syme, G. J. (2003) *Social Values and Impact Study South West Yarragadee Blackwood Groundwater Area. The Results of the South West and Perth Community Surveys*. Australian Research Centre for Water in Society, CSIRO.
61	Nijkamp, P., Vingidni, G., and Nunes, P. (2008) Economic valuation of biodiversity: A comparative study. *Ecological Economics* 67(2): 217-231.
62	Nunes, P. and van den Bergh, J. (2001) Economic valuation of biodiversity: sense or nonsense? *Ecological Economics* (39): 203-222.
63	Ongerth, H. and Ongerth, J. (1982) Health Consequences of Wastewater Reuse. *Annual Review of Public Health* (3): 419-444.
64	O'Toole, J., Leder, K., and Sinclair, M. (2007) Recycled water and human health effects. *Australian Family Physician* 36(12): 998-1000.
65	Pandey, D. N., Gupta, A., and Anderson, D. (2003) Rainwater harvesting as an adaptation to climate change. *Current Science* 85(1): 46-59.
66	Point Carbon. Carbon Market Research. Accessed 23 March, 2010. *www.pointcarbon.com/research/carbonmarketresearch/*
67	Prime Minister's Science, Engineering and Innovation Council (PMSEIC) (2003) *Recycling Water for Our Cities*. Accessed 15 March, 2010. http://www.innovation.gov.au/Section/pmseic/documents/recyclingwaterforourcities.pdf
68	Retamal, M., Glassmire, J., Abeysuriya, K., Turner, A., and White, S. (2009) *The Water-Energy Nexus - Investigation into the Energy Implications of Household Rainwater Systems, Final Report*. Institute for Sustainable Futures, University of Technology, Sydney.
69	Rein, F. (1999) An Economic Analysis of Vegetative Buffer Strip Implementation Case Study: Elkhorn Slough, Monterey Bay, California. *Coastal Management* 27(4): 377-390.
70	Ritchie, S., Montgomery, B., and Walsh, I. (2002) Production of Mosquitoes in Rainwater Tanks and Wells on Yorke Island, Torres Strait: Preliminary Study. *Environmental Health* 2(2): 13-18.
71	River, N. and Sawyer, D. (2008) Pricing Carbon: saving green. *A Carbon Price to Lower Emissions, Taxes and Barriers to Green Technology. David Suzuki Foundation.*
72	Rousseau, D.P.L., Lesage, E., Story, A., Vanrolleghem, P.A., and De Pauw, N. (2008) Constructed wetlands for water reclamation. *Desalination* (218): 181-189.
73	Sazakli, E., Alexopoulos, A., and Leotsinidis, M. (2007) Rainwater harvesting, quality assessment and utilization in Kefaloni a Island, Greece. *Water Research* (41): 2039-2047.
74	Shäfer, A.I. and Beder, S. (2006) Relevance of the precautionary principle in water recycling. *Desalination* (187): 241-252.
75	Stenekes, N., Colebatch, H.K., Waite, D., and Ashbolt, N.J. (2006) Risk and Governance in Water Recycling: Public Acceptance Revisited. *Science Technology Human Values* (31): 107-134.
76	Straton, A. and Zanden, K. (2009) The value of Australia's tropical river ecosystem services. TRaCK 2.1 Assets and Values.
77	Tapsuwan, S., Ingram, G., and Brennan, D. (2007) Valuing Urban Wetlands of the Gnangara Mound: A Hedonic Property Price Approach in Western Australia, In AARES 51st Annual Conference.
78	Tam, V.W.Y., Tam, L., and Zeng, S.X. (2009) Cost effectiveness and tradeoff on the use of rainwater tank: An empirical study in Australian residential decision-making. *Resources, Conservation and Recycling* 54(3): 178-186.
79	Taylor, A. (2005) Guidelines for E*valuating the Financial, Ecological and Social Aspects. Technical Report*. Cooperative Research Centre for Catchment Hydrology. Accessed 15 March, 2010. http://www.catchment.crc.org.au/archive/pubs/1000169.html
80	Taylor, R. (2007) Catching up with the new Carbon Cycle. *ECOS* (138): 12-15.
81	The World Bank (2003) *Economic Valuation of the Health Benefits of Reduction in Air Pollution,* South Asia Urban Air Quality Management, Briefing Note No. 12, Report no. 25692.
82	Toze, S. (2004) Reuse of effluent water - benefits and risks. *"New directions for a diverse planet". Proceedings of the 4th International Crop Science Congress, Brisbane, Australia.* Accessed 21 February, 2010. http://www.cropscience.org.au/icsc2004/symposia/1/5/2086_toze.htm
83	Vaes, G. and Berlamont, J. (1999) The Impact of Rainwater Reuse on CSO Emissions. *Water Science and Technology* 39(5): 57-64.
84	Water Services Association of Australia (WSAA) (2006) *Refilling the Glass: Exploring the issues surrounding water recycling in Australia*. Water Services Association of Australia, Position Paper No. 02.

REFERENCES

Angelakis, A., Bontoux, L., and Lazarova, V. (2003) Challenges and prospectives for water recycling and reuse in EU countries. *Water, Science and Technology: Water Supply* 3(4): 59-68.

Aryal, R., Kandasamy J, Vigneswaran, S. (2010) Urban Stormwater Quality, Standards and Treatment. *Korean Journal of Chemical Engineering* 27(5), 1343-1359.

Asano, T. (2001) Water from (waste) water- the dependable water resource, *11th Stockholm Water Symposium*.

Asano, T. and Cotruvob, J.A. (2004) Groundwater recharge with reclaimed municipal wastewater: health and regulatory considerations. *Water Research* 38(8):1941-1951.

Australian Water Association (AWA) (2010) Biosolids Management. Accessed 27 May, 2010. http://www.awa.asn.au/AM/Template.cfm?Section=Biosolids_Management

Barten, J., 1986. Nutrient removal from urban stormwater runoff by wetland filtration: The Clear Lake restoration project. *Lake Reservoir Manage*., 2: 297-305.

Beyer, M., Lohrengel, B., Nghiem, L. (2010) Membrane fouling and chemical cleaning in water recycling applications, *Desalination* 250: 977–981.

Bixioa C, Thoeyea C, De Koningb J, Joksimovicb D, Savicc D, Wintgensd T, *et al*. (2006) Wastewater reuse in Europe. *Desalination* 187: 89–101.

Blue Scope Steel 2010 (2010) Rain Water Tanks - Life Cycle Analysis. Accessed May 13, 2010. http://www.bluescopesteel.com.au/go/building-products/rainwater-harvesting/life-cycle-analysis-for-rainwater-tanks/rain-water-tanks-life-cycle-analysis/objectID/B303F6BA-88F6-475D-AEE714D5A6DE2644.

BMT WBM (2010) Total Water Cycle Management Strategy for Moreton Bay Regional Council. R.B17909.001.02.TWCM Strategy.doc. December 2010. Document prepared for the Queensland Water Commission.

BMT WBM (2012) Total Water Cycle Management Plan for Moreton Bay Regional Council. R.B18282.002.02. June 2012. Document prepared for the Queensland Water Commission.

Brennan, L., Lisson, S., Khan, S., Carberry, P., and Bristow, K. (2003) An economic and environmental evaluation of the benefits and risks of recycled-water irrigated crop production on the Darling Downs. CSIRO.

Brown, C. (2009) *Recycled Water: Risks, benefits, economics and regulation by system scale*. Recycling of Water: New Zealand Land Treatment Collective Conference, Taupo, New Zealand.

Brown, R. (2005) Impediments to Integrated Urban Stormwater Management: The Need for Institutional Reform. *Environmental Management* 36(3): 455-468.

Bryan, B. and Kandulu, J. (2009) Cost-effective alternatives for mitigating Cryptosporidium risk in drinking water and enhancing ecosystem services. *Water Resources Research* 45(8).

Byard, R. (2008) Rainwater tank drowning. *Journal of Forensic and Legal Medicine* (15): 533-534.

Cammerman, N. (2009) Integrated Water Resource Management and the Water, Energy, Climate Change Nexus. Thesis: Masters of Integrated Water Management Program, UQ.

Chanan, A. and Woods, P. (2006). Introducing total water cycle management in Sydney: a Kogarah Council initiative. *Desalination* 187(1-3), 11-16.

Chocat, C., Ashley, R., Marsalek, J., Matos, M.R., Schilling, W. and Urbonas, B. (2007) Toward the Sustainable Management of Urban Storm-Water. *Indoor and Built Environment* 16: 273

Coombes, P. (2007) Energy and Economic Impacts of Rainwater Tanks on the Operation of Regional Water Systems. *Australian Journal of Water Resources* 11(2): 177-191.

Coombes, P.J., Argue, J.R. and Kuczera, G. (2000) Figtree Place: a case study in water sensitive urban development. *Urban Water* 1(4): 335-343.

Coombes, P. and Barry, M. (2008) 'The relative efficiency of water supply catchments and rainwater tanks in cities subject to variable climate and the potential for climate change', *Australian Journal of Water Resources*, Vol. 12, No. 2, pp 85 – 100.

Coombes, P.J., Kuczera, G., Kalma, J.D., and Argue, J.R. (2002) An evaluation of the benefits of source control measures at the regional scale. *Urban Water* (4): 307-320.

Coombes, P.J. and Kuczera, G. (2003) A Sensitivity Analysis of an Investment Model Used to Determine the Economic Benefits of Rainwater Tanks. *Australia 28th International Hydrology and Water Resources Symposium*, The Institution of Engineers.

Coultas, E.H., Maheepala, S., Neumann L.E., Beal C.D., Stewart, R., Chong, M.N. and Sharma, A.K. (2012) *Towards the Quantification of Rainwater Tank Yield in South East Queensland by*

Considering the Spatial Variability of Tanks. Conference Paper MODSIM 2011, Perth, Australia, 12-16 December 2011.

Daniels, P., Porter, M., Bodsworth, P. and Coleman, S. (2012). *Externalities in Sustainable Regional Water Strategies: A compendium of externality impacts and valuations.* Urban Water Security Research Alliance Technical Report No. 42.

Daniels, P., Porter, M. and Bodsworth, P. (2012). *Externalities in Sustainable Regional Water Strategies: Report 2: Application of a simple methodology.* Urban Water Security Research Alliance Technical Report No. 81

Davis, C. K. (2006) *Ethical Dilemmas in Water Recycling*. Water Supply and Treatment Division, San Francisco Public Utilities Commission, San Francisco, US.

Dimitriadis, Dr. S. (2005) Issues encountered in advancing Australia's water recycling schemes. Information analysis and advice for the Parliament Research Brief. Parliament of Australia, Department of Parliamentary Services Parliamentary Library. Report no. 2, 2005 - 06.

Environment Australia (2002) *Introduction to Urban Stormwater Management in Australia*. Department of the Environment and Heritage, Commonwealth of Australia, Canberra. Accessed 3 May, 2010. http://www.environment.gov.au/coasts/publications/stormwater/pubs/stormwater.pdf.

Environmental Protection and Heritage Council (2007) Australian Guidelines for water recycling: Managing Health and Environmental risks (Phase 2) augmentation of drinking water supplies. NRM National Water Quality Management Strategy.

Eroksuz, E. and Rahman, A. (2010), Rainwater tanks in multi-unit buildings: A case study for three Australian cities, *Resources, Conservation and Recycling* 54: 1449–1452.

Evans, C.A., Coombes, P.J., and Dunstan, R.H. (2006) Wind, rain and bacteria: The effect of weather on the microbial composition of roof-harvested rainwater. *Water Research* (40): 37-44.

Fletcher, T.D., Deletic, A. and Hatt, B.E. (2004) *A Review of Stormwater Sensitive Urban Design in Australia*. Water Conservation and Reuse Research Program.

Fletcher, T.D., Mitchell, V.G., Deletic, A., Ladson, T.R., and Se ´ ven, A. (2007) Is stormwater harvesting beneficial to urban waterway environmental flows? *Water Science and Technology* 55(4): 265-272.

Furumai, H. (2008) Rainwater and reclaimed wastewater for sustainable urban water use. *Physics and Chemistry of the Earth* (33): 340-346.

Gardiner, A. (2009) Domestic Rainwater Tanks: Usage and Maintenance Patterns in South East Queensland. *Water* 36(1): 151-156.

Gardner, T. (2002) Some examples of water recycling in Australian urban environments - A step towards environment sustainability. Queensland Department of Natural Resources and Mines.

Gardner, T and Vieritz, A. (2010) The role of rainwater tanks in Australia in the 21st Century. *Architectural Science Review*, 53 1-20.

Giacalone, K. ,Mobley, C., Sawyer, C., Witte, J., Eidson, G. (2010) Survey Says: Implications of a Public Perception Survey on Stormwater Education Programming. *Journal of Contemporary Water Research & Education* 146 (1): 92–102.

Goodall, M. (2000) A Drinking Water Investigation. *New South Wales Public Health Bulletin* 11(7): 124-126.

Greenway, M. (2010) Wetlands and Ponds for Stormwater Treatment in Subtropical Australia: Their Effectiveness in Enhancing Biodiversity and Improving Water Quality? *Journal of Contemporary Water Research & Education* 146 (1): 22–3.

Hall, M., West, J., Lane, J., de Haas, D. and Sherman, B. (2009). *Energy and Greenhouse Gas Emissions for the SEQ Water Strategy.* Urban Water Security Research Alliance Technical Report No. 14.

Hall, M.R. (2012). *Extended Cost-Effectiveness of Water Supply Options: Case Study of the Total Water Cycle Management Plan for Moreton Bay Regional Council.* Urban Water Security Research Alliance Technical Report No. 88.

Hallmann, M., Grant, T., and Alsop, N. (2003) Yarra Valley Water Life Cycle Assessment and Life Cycle Costing of Water Tanks as a Supplement to Mains Water Supply. Centre for Design at RMIT University, Melbourne.

Hambly, A., Henderson, R., Storey, M., Baker, A., Stuetz, R. and Khan, S. (2010) Fluorescence monitoring at a recycled water treatment plant and associated dual-distribution system – implications for cross-connection detection. *Water Research* 44(18): 5323-5333.

Hampton, G. (2010) Discursive Evaluation of Water Recycling. *Qualitative Research Journal* 10 (2): 65-81.

Hatt, B., Deletic, A., and Fletcher, T. (2006) Integrated treatment and recycling of stormwater: a review of Australian practice. *Journal of Environmental Management* (79): 102-113.

Hausler, G. (2006*) Review of Use of Stormwater and Recycled Water As Alternative Water Resources.* 8 June 2006. Draft Report. SEQ Regional Water Supply Strategy. Cardno (QLD) Pty Ltd, Toowong. Job No. 2748-43

Helmreich, B. and Horn, H. (2009) Opportunities in rainwater harvesting. *Desalination* 248(1-3): 118-124.

Hurlimann, A. (2007) Time for a Water Re-'Vision. *Australian Journal of Environmental Management* (14): 14-21.

Jang, T., Lee, S.B., Sung, C.H., Lee, H.P., Park, S. (2010) Safe application of reclaimed water reuse for agriculture in Korea. *Paddy Water Environ.* 8: 227–233.

Johengen, T. and LaRock, P. (1993) Quantifying nutrient removal processes within a constructed wetland designed to treat urban stormwater runoff. *Ecological Engineering*, 2, 347-366.

Kahinda, J.M., Taigbenu, A., and Boroto, J. (2007) Domestic rainwater harvesting to improve water supply in rural South Africa. *Physics and Chemistry of the Earth* 32(15-18): 1050-1057.

Khastagir, A. and Jayasuriya, L. (2010) Impacts of using rainwater tanks on stormwater harvesting and runoff quality. *Water Sci Technol.* 62(2):324-9.

Knights, D. and Wong, T. (2008) Drought Proofing Cities: Desalination Versus Rainwater Tanks - a Challenge to Water Supply Managers. *Australian Journal of Water Resources* 12(2): 1010-109.

Kuczera, G. (2008) Urban Water Supply Drought Security: A Comparative Analysis of Complimentary Centralised and Decentralised Storage Systems. Proceedings of *Water Down Under 2008: Incorporating 31st Hydrology and Water Resources* Symposium, and, 4th International Conference on Water Resources and Environment Research (Adelaide, S.A. 15-17 April, 2008) pp. 1532-1543

Lane J., de Haas, D. and Lant, P. (2010) *Life Cycle Assessment of the Gold Coast Urban Water System.* Urban Water Security Alliance Technical Report.

Le-Minh, N., Khan, S., Drewes, J. and Stuetz, R. (2010) Fate of antibiotics during municipal water recycling treatment processes. *Water Research* 44(15): 4295-4323.

Lloyd, S.D., Wong, T.H.F and Chesterfield, C.J. (2002) *Water Sensitive Urban Design - A Stormwater Management Perspective*. Cooperative Research Centre for Catchment Hydrology Melbourne Water Corporation. Industry Report 02/10.

Luoma,S.N. and Cloern,J.E. (1982) 'The impact of waste- water discharge on biological communities in San Francisco Bay' in W.J.Kockelman,T.J.Conomos and A.E.Leviton(eds.), *San Francisco Bay: Use and Protection,* American Association for the Advancement of Science, San Francisco.

Lye, D. (2009) Rooftop runoff as a source of contamination: A review. *Science of the Total Environment* (407): 5429-5434.

Makropoulos, C. and Butler, D. (2010) Distributed Water Infrastructure for Sustainable Communities. *Water Resource Management* 24: 2795 – 2816

Marsden Jacob Associates (2007a) *The cost-effectiveness of rainwater tanks in urban Australia*, A report prepared by Marsden Jacob Associates for the National Water Commission. 22 February 2007.

Marsden Jacob Associates (2007b) The economics of rainwater tanks and alternative water supply options, Camberwell, Victoria.

Mikkelsen, P.S., Vezzaro, L. Birch, H., Eriksson, E., Lützhøft, H., Høg, H. and Sharma, A.K. (2012) Monitoring, chemical fate modelling and uncertainty assessment in combination: a tool for evaluating emission control scenarios for micropollutants in stormwater systems. Paper presented at the 7th International Conference on Water Sensitive Urban Design 21–23 February 2012. Melbourne Cricket Ground, Melbourne, Australia.

Miller, E. and Buys, L. (2008) Water-Recycling in SEQ, Australia: What do Men and Women Think. *Rural Society* 18(3): 220-229.

Mitchell, C. and Rahman, A. (2007) Rainwater Tanks: Costs and Benefits. *Issues* 79(June): 41-42.

Mitchell, V., Deletic, A., Fletcher, T., Hatt, B., and Mcarthy, D. (2007) Achieving multiple benefits from stormwater harvesting. *Water Science and Technology* 55(4): 135-144.

MBRC (Moreton Bay Regional Council) (2012) "Our Council". Web pages accessed October 20, 2012. http://www.moretonbay.qld.gov.au/general.aspx?id=4718

Naji, F. and Lustig, T. (2006) On-site water recycling - a total water cycle management approach. International Conference on Integrated Concepts on Water Recycling.

Nanbakhsh, H. (2005) Design Comparison of Experimental Stormwater Detention Systems in Treating Concentrated Road Runoff. *Iranian Journal of Environmental Health, Science and Engineering* 2(3): 169-176.

Nancarrow, B. E., Leviston, Z., Tucker, D., Greenhill, M. P., Price, J., and Zidic, D. (2007) Community Acceptability of the Indirect Potable Use of Purified Recycled Water in South East Queensland and Preferences for Alternative Water Sources: A Baseline Measure. Urban Water Research Alliance, Technical Report No. 1.

Nghiem, L.D., McCutcheon, J., Schäfer, A.I., and Elimelech, M. (2004) The role of endocrine disrupters in water recycling: risk or mania? *Water Science and Technology* 50(2): 215-220.

Nijkamp, P., Vingidni, G., and Nunes, P. (2008) Economic valuation of biodiversity: A comparative study. *Ecological Economics* 67(2): 217-231.

O'Toole, J., Leder, K., and Sinclair, M. (2007) Recycled water and human health effects. A*ustralian Family Physician* 36(12): 998–1000.

Ongerth, H. and Ongerth, J. (1982) Health Consequences of Wastewater Reuse. *Annual Review of Public Health* (3): 419-444.

Page, D., Dillon, P., Toze, S., Bixio, D., Genthe, B., Jiménez Cisneros, B., Wintgens, T. Valuing the subsurface pathogen treatment barrier in water recycling via aquifers for drinking supplies. Water Res 44(6): 1841-52.

Pasqualino, J.C., Meneses, M., Castells, F. Life Cycle Assessment of Urban Wastewater Reclamation and Reuse Alternatives (2011) *Journal of Industrial Ecology*, 15 (1), 49-63.

Pittman, J. and Mccormick, R.J., 2010. Ecosystem Service Valuation Concepts and Methods. In Kapustka, L. and Landis, W. (Eds.) Environmental Risk Assessment and Management from a Landscape Perspective. San Francisco: John Wiley & Sons, Inc., pp. 361-379.

Price, J., Green, M.J., Leviston, Z., Fielding, K., and Gardner, J. (2011). Communication and Community Responses to Recycled Water. Urban Water Security Research Alliance Technical Report No. 58. Report to the Qld Water Commission. Queensland, Australia.

Prime Minister's Science, Engineering and Innovation Council *(*PMSEIC) (2003) *Recycling Water for Our Cities*. Accessed 15 March, 2010. http://www.innovation.gov.au/Section/pmseic/documents/recyclingwaterforourcities.pdf

Queensland Government (2009) *Environmental Protection (Water) Policy 2009*. Subordinate Legislation 2009 No. 178 made under the Environmental Protection Act 1994.

Queensland Water Commission (2009) *South East Queensland Water Strategy*. Queensland Water Commission, Brisbane, QLD. Accessed 3 May, 2010. http://www.qwc.qld.gov.au/SEQWS

Retamal, M., Glassmire, J., Abeysuriya, K., Turner, A., and White, S. (2009) *The Water-Energy Nexus - Investigation into the Energy Implications of Household Rainwater Systems, Final Report*. Institute for Sustainable Futures, University of Technology Sydney.

Ritchie, S., Montgomery, B., and Walsh, I. (2002) Production of Mosquitoes in Rainwater Tanks and Wells on Yorke Island, Torres Strait: Preliminary Study. *Environmental Health* 2(2): 13-18.

Rousseau, D.P.L., Lesage, E., Story, A., Vanrolleghem, P.A., and De Pauw, N. (2008) Constructed wetlands for water reclamation. *Desalination* (218): 181-189.

Russell, R. (1999) Constructed wetlands and mosquitoes: Health hazards and management options-An Australian perspective. *Ecological Engineering* (12): 107-124.

Sazakli, E., Alexopoulos, A., and Leotsinidis, M. (2007) Rainwater harvesting, quality assessment and utilisation in Kefalonia Island, Greece. *Water Research* (41): 2039-2047.

Schlacher, T.A., Liddell, B., Gaston, T.F., and Schlacher-Hoenlinger, M. (2005) Fish track wastewater pollution to estuaries. *Oecologia* 144(4): 570-581.

Shäfer, A.I. and Beder, S. (2006) Relevance of the precautionary principle in water recycling. *Desalination* (187): 241-252.

Siebert, E., Young, M., and Young, D. (2000) *Exposure Draft - Draft Guidelines for Managing Externalities - Restoring the balance*. Department of the Environment, Water, Heritage, and the Arts. Accessed 23 November, 2009. http://www.environment.gov.au/water/publications/action/externalities.html.

Stewart, R.A. (2011) *Verifying potable water savings by end use for contemporary residential water supply schemes*, Waterlines report, National Water Commission, Canberra.

Tam, V.W.Y., Tam, L., and Zeng, S.X. (2009) Cost effectiveness and tradeoff on the use of rainwater tank: An empirical study in Australian residential decision-making. *Resources, Conservation and Recycling* 54(3): 178-186.

Tanner, R, C., Leinster, S. & Harris, D. H. (2010). Stormwater Harvesting as a Water Source for South East Queensland. *Water*, April, 67 - 74.

Taylor, A. (2005) *Guidelines for Evaluating the Financial, Ecological and Social Aspects. Technical Report.* Cooperative Research Centre for Catchment Hydrology, Canberra. Accessed 15 March, 2010. http://www.catchment.crc.org.au/archive/pubs/1000169.html.

Tjandraatmadja G, Cook S, Ho A, Sharma A and Gardner T, (2009). *Drivers for Decentralised Systems in South East Queensland.* Urban Water Security Research Alliance Technical Report No. 13.

Toze, S. (2004) Literature review on the Fate of Viruses and Other Pathogens and Health Risks in Non-Potable Reuse of Storm Water and Reclaimed Water, Australian Water Association and CSIRO, Australian Water Conservation and Reuse Research Program.

Toze, S. (2006) Water reuse and health risks - real vs. perceived, CSIRO Land and Water, Floreat, W.A. *Desalination 187: 41 – 51.*

Uhlmann, V. and Head, B.W. (2011). Water Recycling: Recent History of Local Government Initiatives in South East Queensland. Urban Water Security Research Alliance Technical Report No. 45. Report to the Qld Water Commission. Queensland, Australia.

Vaes, G. and Berlamont, J. (1999) The Impact of Rainwater Reuse on CSO Emissions. *Water Science Technology* 39(5): 57-64.

Villarreal, E. L. and Dixon, A. (2005) Analysis of a rainwater collection system for domestic water supply in Ringdansen, Norrköping, Sweden. *Building and Environment* (40): 1174-1184.

Water by Design (2010) *Total Water Cycle Management Planning Guideline for South East Queensland (Version 1, December 2010).* Department of Environment and Resource Management, Brisbane, Queensland.

Water Services Association of Australia (WSAA) (2006) Refilling the Glass: Exploring the issues surrounding water recycling in Australia. Position Paper No. 02.

Young, M. 2000 Managing Externalities: Opportunities to Improve Urban Water Use, CSIRO Urban Water Program

Zhao H, O'Halloran R, Fogelman S, Toscas P, Zhang S and Burn S, (2009). Water Quality Monitoring in the Western Corridor Recycled Water Scheme. Urban Water Security Research Alliance Technical Report No. 11. Report to the Qld Water Commission. Queensland, Australia.