Externalities in Sustainable Regional Water Strategies: A Compendium of Externality Impacts and Valuations

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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.

For more information about the:

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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.

C. Davis

Chris Davis
Chair, Urban Water Security Research Alliance

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LIST OF ACRONYMS

BNR	Biological Nutrient Removal
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DERM	Department of Environment and Resource Management
EPA	Environmental Protection Agency
GHG	Greenhouse Gases
GU	Griffith University
IUWM	Integrated Urban Water Management
LCA-IM	Life Cycle Analysis and Integrated Modelling
PRW	Purified Recycled Water
QWC	Queensland Water Commission
SCC	Social cost of carbon
SEQ	South East Queensland
SEQ-RP	South East Queensland Regional Plan
SEQWS	South East Queensland Water Strategy
TEV	Total Economic Value
UQ	The University of Queensland
UWSRA	Urban Water Security Research Alliance
VSL	Value of a statistical life
WSP	Water Service Provider
WSUD	Waste Sensitive Urban Design
WTP	Willingness to pay
WWTP	Wastewater Treatment Plant

EXECUTIVE SUMMARY

There is continued interest in identifying and implementing long-term, cost-effective options for secure and high quality water resources for South East Queensland (SEQ). In recent years, there has been a shift away from traditional approaches, which rely heavily on technological and physical problem-solving, towards models which incorporate sustainability principles (Gleick, 2000). Integration and interdisciplinary coordination are key aspects of the new management approaches. No longer is water management merely a case of ensuring supply. In a world where humanity is confronted by growing environmental scarcity and social interconnectedness, there is an increasing requirement to thoroughly assess the full impacts and trade-offs associated with alternative resource management strategies.

To comprehensively assess the consequences of resource management strategies across communities and over the long-term, it is necessary to consider both private financial costs and benefits, and other less direct, but often very significant impacts on human welfare. Effects that are not taken into account directly in market-place transactions are known as "externalities". Externalities typically involve welfare effects on others not involved in the transaction; often effect long-term or unknown outcomes upon community well-being and are part of complex cause-effect chains (for example, the positive recreational gardening impacts of residential rainwater tanks).

This report focuses on the compilation and presentation of the background information required to prepare basic externality analyses to supplement and strengthen the assessment of sustainable water management options. The two main sets of data presented to support this process are: (1) the identification of an extensive range of externalities related to water servicing options; and (2) existing economic valuations of these externality effects. The compendium provides a comprehensive review of existing research into the identification and economic assessment of externalities pertinent to the adoption of seven different water supply options under consideration in the SEQ, including stormwater harvesting, rainwater tanks, centralised wastewater recycling, dams, desalination, groundwater and greywater reuse.

The research undertaken in this report builds on existing frameworks developed for the analysis and policy assessment of externalities related to water (e.g. Taylor and Fletcher 2005; Sharma, Grant, Grant, Pamminger and Opray 2009; Young 2000) and extensive databases of generalised externality economic valuations such as Environment Canada's EVRI (the Environmental Valuation Reference Inventory) and the New South Wales EPA's ENVALUE environmental valuation database.

Additional discussion of a methodology for potential consideration and integration of externality impacts into general water management policy processes will be provided in the companion report by Daniels and Porter (2012) - *Externalities in Sustainable Regional Water Strategies: Application of a simple methodology* (in publication).

Section 3 of the compendium consists of a set of tables listing all the **externality effects** that have been identified for individual water servicing options in the literature surveyed. Each study option has been analysed to identify externality types and characteristics that are likely to be relevant and significant for that option. The impacts of options are assessed both in general terms and across the various stages of their life cycles. The life cycle and operational phases typically included collection and sometimes storage, treatment, use and distribution, and decommissioning. The externalities associated with each option were identified by surveying relevant existing research and findings in water-related studies and through technical analysis of the option characteristics and technologies. The list of individual externalities is classified according to an externality type classification reflecting the focus and categories commonly used in related research (for example, greenhouse gas emissions (GHG), nutrients (N) and recreation (R) impacts).

For each water service option, two matrices are provided. The first is an extended version which provides some brief comments and description about the individual externalities. The second version presents only the symbols and the reference source details. The tables also indicate whether the externality tends to be positive (+) or negative (-); and if the effect predominantly occurs upstream (↑), downstream (↓) or in the localised area (◙) of the primary option location. Both table formats show reference numbers to identify the relevant sources of information for each externality. Full details of the sources cited can be found at the end of the report.

Section 4 of the compendium presents an extensive listing of **existing economic valuations** for the individual externalities identified in the first part of the analysis. The externality valuations are presented in one overall table and, while classified by type, are not distinguished in terms of the water servicing options to which they are linked.

The valuations are intended to help guide externality analyses and valuation attempts across a wide range of applications and contexts. However, the focus impacts have been selected on the basis of their relevance for water options under consideration for SEQ.

As the foundation for possible ongoing economic assessment, the externality values are first assessed in terms of "average" dollars per biophysical unit (for example, an economic cost of $100 per kg for nitrogen emissions from wastewater recycling). Per unit values are provided here on a benefit or costing transfer basis (that is, from other relevant studies), but they can be calculated, with much more time and expense, from primary research or proxy data (based on the study area and context-specific characteristics). Estimates from cost transfer methods may also be adapted or adjusted on the basis of the unique features and conditions of the study context. Appropriate monetary unit value ranges, or median, modal or other measures of central tendency, would need to be identified for multiplication by total flow, production or other water service metrics.

The economic valuation estimates of the "unintended" impacts captured in externality analysis of water servicing options are presented on the strict proviso that they are just potentially valuable inputs that form one part of the decision-making process for water management. The caveats associated with the conceptual and theoretical problems of economic valuation methodologies, and the limits of drawing valuation estimates from very different geopolitical contexts, must be fully acknowledged.

The externalities identified and/or the valuations can be applied as inputs and background information for a variety of decision-making frameworks such as multiple criteria assessment or cost-benefit analysis. There is significant controversy surrounding the extent to which monetary values for externalities should be used as a basis for policy (Gardner, Hatton, MacDonald and Chung, 2006; Rein 1999). Thus, the externality valuations are provided as a general information base. It is up to the individual practitioners to take the next step of compiling and combining the externalities and valuations in decision-making, if they so wish.

A critical assumption underlying the proposed use of the compendium is that the benefits of externality analysis are not solely dependent on the ability to convert all costs and benefits into dollar values. Indicative monetary values can be very useful in decision-making if there is explicit treatment and awareness of the range of estimated values, the reliability, completeness, and accuracy of underlying data, and the need for specific contextual information on impacts.

Together, the externality identification and valuation tables presented in this compendium provide a useful reference and guide for researchers, planners and decision-makers concerned with the sustainable management of water.

An extract of the summary table (below) in the discussion section demonstrates the type of information available in the compendium, albeit in a condensed form.

Externality Summary Table - Extract

KEY EXTERNALITIES	
RAINWATER TANKS	
• Comparatively higher energy usage than reticulated mains water (mostly due to inefficient pump systems). (All Stages (-, ↑, ↓, ◙)) • Higher greenhouse gas 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 fresh water usage, which 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 (-,◙)) • Health and environmental problems stem from the pollutants and wastes associated with the manufacture of the tanks. (Manufacturing Stages (-,◙)) • Waste disposal is a source pollution and of potential environmental and health contamination risk. (Disposal Stages (-,↓, ◙))	**Main externality types** Greenhouse gas emissions (GHGs), 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 95) • Energy Costs $19.75/MWh (Ref 289)
WASTEWATER RECYCLING	
• Reduced degradation of receiving waters. (Collection and Treatment Stages (+,↓, ◙)) • Additional water resource available to drought constrained farmers and other industries. (Collection and Use Stages (+,◙)) • Risk of soil contamination. (Use Stages (-,↓, ◙)) • Contamination risks and associated health concerns. (Treatment and Use Stages (-,◙)) • Risk of cross-contamination and consequent illness. (Use/ Distribution Stages (-,◙)) • Low levels of community acceptance for 'high-contact' uses, which may lead to feelings of disempowerment. (Use Stages (-,◙)) • Additional nutrients found within recycled water may serve as potential sources of fertiliser for agricultural uses. (Use Stages (+,◙)) • Increased capacity for maintenance of 'green spaces' throughout droughts – amenity and recreational benefits. (Use Stages (+,◙)) • Disposal of concentrate (a by-product) may lead to environmental degradation and high transport requirements. (Waste Management Stages (-,↓, ◙))	**Main externality types** Water Quality (W.Q),Production (P), Health (H),Non-Use (N.U.) **Valuation Examples ($AUD 2010)** • Cost of a visit to emergency room $488.52 (ref 346) • Willing to pay $70.35 increase in annual household water costs for recycled water with high contact uses (Ref 218) • $1073/tonne for average annual point source phosphorus load reduction (Ref 302)

Note: (+) positive or (-) negative externality; (↑) the effect predominantly occurs upstream, (↓) downstream or (◙) in the localised area.

Several gaps in existing research on the evaluation and monetisation of externalities related to water servicing options, relevant to the SEQ context, have been identified, including:

- A general lack of knowledge about biodiversity and ecosystem impacts of the water servicing options.
- Externality and impact research is often weighted towards the political agendas at the time of publication. For example, as dams and water recycling are currently controversial issues, they are subject to a plethora of research specifically looking into public acceptance and water quality issues. An important implication is that options that are subject to controversy may appear more problematic due to research revealing a more extensive range of negative externalities.
- There are very few data available on how water servicing options impact indigenous communities.
- There is a pronounced paucity of research and data on the decommissioning impacts of all supply options reviewed. This is an important life cycle stage (with the potential for serious externalities) and it is unfortunate that there is limited information available in this area.
- There was also a general lack of published life cycle assessment (LCA) studies relating to water servicing options. Information from appropriate LCA studies would provide a valuable input into this type of research and be consistent with integrated water management approaches.

1. INTRODUCTION

Water and oxygen share similarities in the human psyche. As with breathing, people tend to disregard the underlying source of water supply while things are going well. But take it away, and scarcity becomes an over-riding concern. Reliable access to sources of suitable water is essential for meeting basic human needs (such as drinking, food supply, cleaning and cooking), ecological integrity and other functions that enhance welfare.

Within a world fraught with water scarcity, Australia is the driest inhabited continent. Given population growth, a propensity for drought and the potential problems of climate change, there is an increasingly urgent need for the adoption of sustainable water management practices (Sudhakar and Mamatha, 2004 - p946). Past water management practices in Australia have been inefficient, with continuing issues of over-allocation and excessive use (Padowski and Jawitz, 2009 - p99).

The last decade has seen SEQ experience a disturbing water supply scenario as dam levels fell to unprecedented lows (around 17 percent of combined capacity), leaving less than a year's supply available at extant consumption levels (QWC, 2009). As the situation reached emergency levels, many new supply options were introduced or planned in an effort to meet the burgeoning demands of a rapidly growing population. These supply expansion options included desalination plants, new dams and upgrades, purified recycled water (PRW) and a large-scale regional water pipeline grid (QWC, 2009). These measures were planned in addition to a range of demand management and decentralised supply options.

By mid-2009, the 'tides had turned' and enough rain had fallen to lead to a declaration that the drought was over. However, from a strategic planning perspective, a valuable lesson was learnt (QWC, 2010). The fact that the precarious situation of the "Millennium Drought" emerged within six years of having full dams (that provide around 95 percent of the region's water) instigated a profound recognition of the need for thorough water security planning and heightened awareness of Australia's highly variable rainfall conditions and dependence upon environmental flows. Despite the ending of the drought, the pressures for careful water management still remain from population growth in SEQ (expected to increase by almost 50 percent from a base of three million in 2010) and the likely impacts of climate change and climate variability in the region with the projected growth in atmospheric concentrations of greenhouse gases (DIP, 2009). In addition, the region has a range of water quality issues that impact on multifarious economic and social aspects of the community's welfare. These water quality issues are closely tied to quantitative water supply and use conditions and become integral to effective sustainable water management planning. All of these factors necessitate new management strategies and practices which secure the region's water supply.

Hence, there is continued interest in identifying and implementing long-term, cost-effective options for water security in SEQ. In recent years, there has been a shift away from traditional approaches, which rely heavily on technological and physical problem-solving, towards models which exhibit a greater capability to incorporate sustainability principles (Gleick, 2000 - p127). This trend has also demonstrated greater capability for integration and interdisciplinary coordination (Padowski and Jawitz, 2009 - p99; Teodosiu *et al.*, 2003 - p377). No longer is water management merely a case of ensuring supply. In a world where humanity is confronted by growing environmental scarcity and social interconnectedness, there is an increasing requirement to thoroughly assess the full impacts and trade-offs associated with alternative resource management strategies. Managing water in the best long-term interests of the community is a global challenge and a critical research and policy area.

Any strategy to provide enhanced water security and meet required levels of service will involve trade-offs. Trade-offs often incorporate external or indirect impacts which pose real and significant impacts on well-being. These effects, when not taken into account directly in market-place transactions, are known as "externalities" (see Box 1). Externalities typically involve welfare effects on others not involved in the transaction, and often effect long-term or unknown outcomes upon community well-being and are part of complex cause-effect chains (for example, the positive recreational gardening impacts of residential rainwater tanks).

Box 1. What are externalities?

> *Externalities refer to the effects of benefits and costs of ... resource management activities not directly reflected in the market. An externality occurs when one person's consumption or production behavior affects that of another without any compensation. The price of the ... goods need not reflect its social value in consumption and management due to presence of externalities. ... Therefore, some households may use or consume too much and some households may use or consume too little so that equity outcome ... may be inefficient.*
>
> Dahal (2007, p.62)

Hence, the unintended impacts of externalities often occur as a result of market failure, where costs and benefits of an action are not reflected within market transactions and the affected parties remain uncompensated (Common and Stagl, 2005, p. 327; Siebert, Young and Young, 2000, p.5). Externalities can constitute a benefit (e.g. provision of recreational habitat) or a cost (e.g. the loss of fisheries production due to water pollution). The primary concern which arises from the presence of externalities is that financial measures associated with water (e.g. prices, infrastructure and project costs) fed into decision-making about strategic options do not reflect true costs upon society and the environment (Gardner, McDonald and Chung, 2006, p.3). Thus, it can be indicative of, or lead to, inefficient water resource allocation. It is crucial that these externalities be reflected throughout decision-making and day-to-day management scenarios (Retamal *et al.*, 2009, p.8).

If planning and policy are to be directed towards selecting strategies and options that account for the full long-term interest of society, and are sustainable in practice, then taking externalities into account is critical. One effective procedure for doing this is to identify and assess each possible option available and its magnitude in biophysical terms, followed by a thorough investigation of the potential costs and benefits in terms of trade-offs of other scarce resources for society (including time and labour). This latter effort constitutes the essence of the environmental economic valuation process presented within this compendium. While conversion to dollar values has many limitations, there are significant benefits to society from assessing the likely full direct and indirect effects (or trade-offs) of alternative options.

The need to identify and assess externalities associated with water and other resource management challenges is being widely embraced. For example, a report on energy use by the Institute for Sustainable Futures declares:

> *We are currently at a critical juncture, where the diverse portfolio of supply and demand-side options currently being invested requires significant investigation in terms of water savings/yield, energy usage, greenhouse gas implications and economic, social and environmental costs and benefits (Retamal et al., 2009 - p8).*

1.1 Report Aim

This report comprises a detailed compendium of the relevance, nature, and value of water-related externalities. It is intended as a resource for widespread application in assisting researchers, planners and other key decision-makers in the successful management of water services. The compendium provides a comprehensive review of existing research into the identification and economic assessment of externalities pertinent to the adoption of seven different water supply options under consideration in the SEQ. These options include stormwater harvesting, rainwater tanks, centralised wastewater recycling, dams, desalination, groundwater and greywater reuse.

This exercise is valuable in helping to identify information/data gaps and opportunities for the effective use of externality dollar values and in broader decision-making approaches such as multiple criteria assessment (MCA). Valuation data is useful for water practitioners as it can facilitate the comparison of costs and benefits across options. The values and externality identification toolkits, as provided in this compendium, can be fed into decision-making and policy processes to assist in sustainable water management (given limitations outlined throughout the report). The research and analysis outputs are influenced by the study focus on South East Queensland, but the systematic overview and summaries will be of widespread interest and application.

Detailed information about externalities and estimated costs and benefits associated with specific water servicing options will be a growing part of the scope of water researchers, policy-makers and practitioners (Retamal *et al.*, 2009 - p8). Specifically, it will be intrinsic for fulfilling the specific requirements and guidelines specified in the *Water Act 2000* which states that regional water supply assessments should consider environmental, social and economic factors (*Water Act 2000,* Section 346 (3,e, i) - p269). It will also be of substantial value in the evaluations and decision-making related to the South East Queensland Water Strategy which makes similar stipulations (QWC, 2009 - p29).

The research undertaken in this report builds on existing frameworks developed for the analysis and policy assessment of externalities related to water (e.g. Taylor and Fletcher 2005; Sharma, Grant, Grant, Pamminger and Opray 2009; Young 2000) and extensive databases of generalised externality economic valuations such as Environment Canada's EVRI (the Environmental Valuation Reference Inventory) and the New South Wales EPA's ENVALUE environmental valuation database.

The compendium in this report is supported by the simple externality analysis (SEXTAN) methodology outlined in the companion report by Daniels and Porter (2012 in publication).

1.2 Project Context

The compendium has emerged from the research activities supported by the Urban Water Security Research Alliance (UWSRA) – the "Alliance". The Alliance has been formed to align and coordinate water research directed towards the identification and assessment of sustainable water supply strategies for SEQ. A major goal is to inform decision-making and the efficacious implementation of the objectives, approaches and options embraced in the SEQ Water Strategy (QWC, 2009).

The background research has been part of the Life Cycle Assessment – Integrated Modelling (LCA-IM) project. This project has brought together researchers from the University of Queensland (UQ), Griffith University (GU), and the Commonwealth Scientific and Industrial Research Organisation (CSIRO). The LCA-IM project has targeted the provision of methodologies for quantifying water flows, nutrient discharges, energy use and greenhouse gas (GHG) emissions of different urban water management options in an integrated life cycle perspective (within the total water cycle context). The LCA-IM project involves the development and testing of methodologies for quantifying (including economic quantification where possible) the major service, biophysical, and socioeconomic outcomes of a range of potential alternative urban water management options for SEQ. Specifically, it has focused on the Logan-Albert catchment within the wider SEQ region.

Two other major aspects of the LCA-IM work have been: (1) modelling of water quantity and quality linked to the major alternative options; and (2) the estimation of biophysical emissions and other resource requirements of the supply options. The biophysical emissions and water quality consequences linked to quantitative changes from potential options established the basis for a more detailed externality analysis and economic valuation assessment of the options being considered in the study area. The Alliance research in this study area has focused specifically on nutrients and sediments, and energy and greenhouse gas emission implications. A significant role for the preparation of the detailed compendium of externalities and valuation estimates in this report has been to feed data into the more focused costing evaluations undertaken by the project team. However, the outputs from the research will have extensive application for any planners and researchers investigating and assessing options for sustainable water management. Again, it is important to emphasise that the information presented in this study is intended for exploratory economic appraisal of per biophysical unit externalities associated with different strategic options, rather than a comprehensive decision-making tool in itself.

1.3 Report Structure

This report is structured to enable quick access to the specific information required. A substantial part of the report is presented as a series of major tables split into two major components of the compendium: (1) the identification and nature of relevant externalities for each option; and (2) the economic value estimates for these externalities (per biophysical unit). The externality value estimates are categorised by type of externality but are not differentiated according to a specific option. Instead, they are combined into one large table. The tables are complemented by discussion and review of major features and findings to help orient the user.

After a description of the approach used to compile the compendium, the major findings are presented in tabular form in Sections 3 and 4. Section 5 summarises some of the major methodological implications and results and provides a preliminary discussion of the potential application of the externality analysis information for strategic planning and decision-making related to water resources.

The externality identification and valuation information provided in this report is supported by a proposed methodology for application in the companion water externalities report by Daniels and Porter (2012 in publication).

2. METHODOLOGY

2.1 Overview

This compendium is aimed at providing water managers, scientists, and practitioners with a detailed reference to help incorporate the full range of costs and benefits into option and scenario assessment and decision-making. The focus is upon externalities, or those effects beyond direct financial costs and returns associated with water service scenarios. 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 the avoidance of unexpected costs later in the project cycle (Siebert, Young and Young, 2000). The research has targeted the SEQ context and the results presented have been influenced accordingly.

There have been many other efforts at developing and applying TBL assessment frameworks related to water servicing management. In addition, there also some existing major published and on-line databases or inventories of benefit and cost transfer valuation estimates.

The compendium and accompanying methods provided in our reports are not intended to compete with or replace these studies. Each existing approach has its own unique sphere of relevance and set of limitations. The externality list and valuation information linked to our seven specific water supply options, and the proposed SEXTAN method, are provided to complement and build on this existing work. It is important to note that the objective and focus of the research here is to facilitate the specification and policy application of a comprehensive and accessible set of externality impacts and valuations for many of the major water servicing options relevant to the Australian context.

In terms of externality lists and economic valuations covering water resources, two of the major existing databases or "infobases" are: (1) EVRI (the Environmental Valuation Reference Inventory), which is managed by Environment Canada and other international experts and organisations; and (2) ENVALUE, developed by the New South Wales (NSW) EPA[1]. Both of these informational sources were instigated in the early to mid-1990s as extensive compilations of the results of international studies for benefit transfer and related adaptations, or to assist in primary research within the context under study. The stated purpose of ENVALUE is to "assist decision makers in government and industry as well as academics, consultants and environmental groups, to incorporate environmental values into cost-benefit analyses, environmental impact statements, project appraisals and overall valuation of changes in environmental quality" (http://www.environment.nsw.gov.au/envalueapp/).

The EVRI and ENVALUE databases contain the results of numerous economic valuation studies relevant to all areas of environmental analysis (not just water). Both systems cover many different geographic contexts and have good search capabilities to enhance selection and modification for benefit transfer to other studies. As an example of their extensive nature, a search of EVRI reveals nearly 1,000 externality valuations under the "freshwater" and "drinking water" categories. However, the output content and format of the results are not well-suited to the TBL assessment of water servicing options. It provides an encyclopaedic format for results under a set of broad general resource categories rather than the systematic compilation of relevant effects and values that can be applied to specific water servicing options (as completed here). The results provided in our water externalities compendium have a standardised per unit (often megalitre) of water quantity (and sometimes quality) provided in contrast to the often diverse formats and comparability issues of results from the major databases.

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[1] For more information on the EVRI and ENVALUE databases see https://www.evri.ca/Other/AboutEVRI.aspx and http://www.environment.nsw.gov.au/envalueapp/ respectively.

ENVALUE does not appear to have been updated since the early 2000s and is also not ideally-suited to the matching of water supply options and externality effects – taking a more general search approach by topics such as “water quality”, “freshwater” and “drinking water”.

Although our externality compendium has been based on extensive technical and literature reviews and covers most major relevant and contemporary effects, it has not included an exhaustive review of all relevant information in the massive EVRI and ENVALUE databases. Hence, we recommend careful searches for additional information from these sources for the TBL assessment of options in water-servicing case studies.

There are many other existing studies that present guidelines and analyse the externalities of specific water servicing options or water management in general, or create frameworks for the structured incorporation of externality procedures within broader decision-making processes. There is considerable variation in the purpose, coverage and approach taken.

Siebert, Young and Young (2000) and Young (2000) provide guidelines for analysing and managing water-related externalities. An overview of their proposed guidelines and framework is provided in Figure 1 below. Taylor (2005) and Taylor and Fletcher (2005) have also developed a TBL method for assessing and including the costs and benefits of urban stormwater in their CRC Catchment Hydrology report. The focus is upon the development of a structured and comprehensive framework for decision-making for a single water servicing option (urban stormwater). As in many water management studies, there is an emphasis upon the multi-criteria analysis (MCA) approach. They compare their framework with the MCA-based European Sustainable Water Industry Asset Resource Decisions (SWARD) program.

Sharma *et al.* (2009) outline a generalised environmental and economic assessment framework developed with an emphasis on externalities associated with water quality and contamination and less on social and the extensive range of other TBL impacts. They also incorporate MCA within their detailed decision-making structure.

Van Bueren and MacDonald (2004) provide a good review of the general nature and types of water externalities. They also present a process for valuing externalities (based on choice modelling valuation results).

The Institute of Sustainable Futures (ISF) also created the “Urban Water Externalities Toolbox” with many similarities to the general approach taken in our reports (Plant, Herriman, and Atherton 2008). Their aim was to develop the methods (tools and processes) for estimating the costs of externalities related to Melbourne’s urban water servicing options (that increase supply or decrease demand). The Toolbox is comprised of a series of detailed and elaborate spreadsheets providing valuation estimates for water managers. At the time of publication, the Toolbox does not appear to be available publicly online.

All of these studies are useful and many key concepts and ideas have been included in the approach taken here. However, none are well-suited to our major objective of this research – the identification, analysis and economic valuation of a comprehensive range of externalities as inputs for the comparative TBL assessment of multiple water servicing options[2]. A key goal is to maintain practicality and simplicity and the open-ended and flexible nature of the individual externality effects and, where possible, their valuation estimates.

Hence, the water servicing option externalities list and valuation compendium and SEXTAN externality analysis method are presented as innovative and valuable contributions to more sustainable water management.

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[2] The elaborate and sophisticated spreadsheets and procedures in the ISF’s Urban Water Externalities Toolbox are far more complex and structured in their intent and application.

Overall, the unique and innovative value of our approach includes the following contributions:

- The detailed tables of relevant potential externality effects and benefit transfer valuations have been specifically prepared for a set of seven widely-used water supply options. Hence, the targeted approach will be of more direct and convenient use to water managers concerned with supply water service planning than generalised lists of externalities associated with water.
- The analysis incorporates greater detail about each externality effect including:
  1. key scientific references and sources for technical descriptions and economic valuations;
  2. the type of impact – classified in a way which is generally consistent with the total economic value concept underpinning most contemporary externality valuation. This classification covers greenhouse gas emissions (GHG); energy (En); water quality (WQ); nutrients (N); production values (P); recreation values (R); amenity values (A); health values (H); ecosystem values (E); biodiversity values (B); non-use values (NU); and other values (O);
  3. the positive, negative or ambivalent nature of the impact; and
  4. whether impacts tend to occur predominantly downstream, upstream, or within the immediate surrounds of the supply infrastructure.
- The full analysis of externalities across life cycle stages of proposed options.
- The analysis has a distinct focus upon the specific physical and human geographic context of SEQ and hence the externality identification process can obviously be applied more directly to water managers in that region (and, to a lesser extent, in Australia in general). However, the externality list tables (and valuations) provide a good basis for customisation and extension to any regional context.
- The relevant externalities for each supply option are tabulated in concise and convenient summary form with a direct link between the externality lists and benefit transfer values.
- The externality identification and valuation compendium is supported by the proposed method for simple externality analysis (SEXTAN) to guide the use of these data.
- The externality analysis and assessment methods are intentionally proposed as being retained in a disaggregated and open-ended way in order to retain as much specific information as possible and maximise the transparency and flexibility of its application in ongoing decision-making activities and policy prescription.
- Our approach is presented as a valuable template for general externality analysis and valuation components of the TBL assessment of multiple waters servicing options – the format, structure and approach is well-suited for ready updating, extension and modification to support decision-making for water managers.

This compendium provides two key sets of information:

1. **The Identification of major externalities associated with alternate water options (Section 3).** Firstly, the compendium provides background descriptions of the range of water servicing options that have been the focus of the Alliance project's SEQ research. This is coupled with an extensive review of relevant water externality research and related literature. This literature provides the foundation for the identification and basic appraisal of the nature of the positive and negative externalities that tend to be associated with the implementation of each of the seven water service options under study – stormwater harvesting, rainwater tanks, wastewater recycling, dams, desalination, groundwater and greywater reuse. 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.
2. **The compilation of a wide range of economic values for significant water-related externalities (Section 4)**. The second major set of results is a detailed compilation of existing estimates of monetary values for each of the externalities identified in Section 3. These valuations were gleaned from a diverse range of existing environmental economic research and estimates were converted to 2010 Australian dollar equivalents in order to facilitate ready comparison.

Together, the description of externalities linked to specific water options and the detailed set of monetary estimates should provide a valuable source book for researchers and planners which can feed valuable information into most decision-making frameworks (including approaches such as multiple criteria assessment and cost-benefit analysis). The results have been compiled as simple matrices that enable quick reference and lookup capabilities for ongoing analysis.

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. Given the emphasis prescribed for the Alliance project, the analysis of externalities has concentrated on greenhouse gas 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, greenhouse gas 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 have been selected on the basis of their identified relevance and application throughout the existing research on water-related externalities (for example, see Young, 2000).

The externality classification draws upon the popular "total economic value" (TEV) approach (Figure 1) (Landell-Mills and Porras, 2002). 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 value functions of nature.

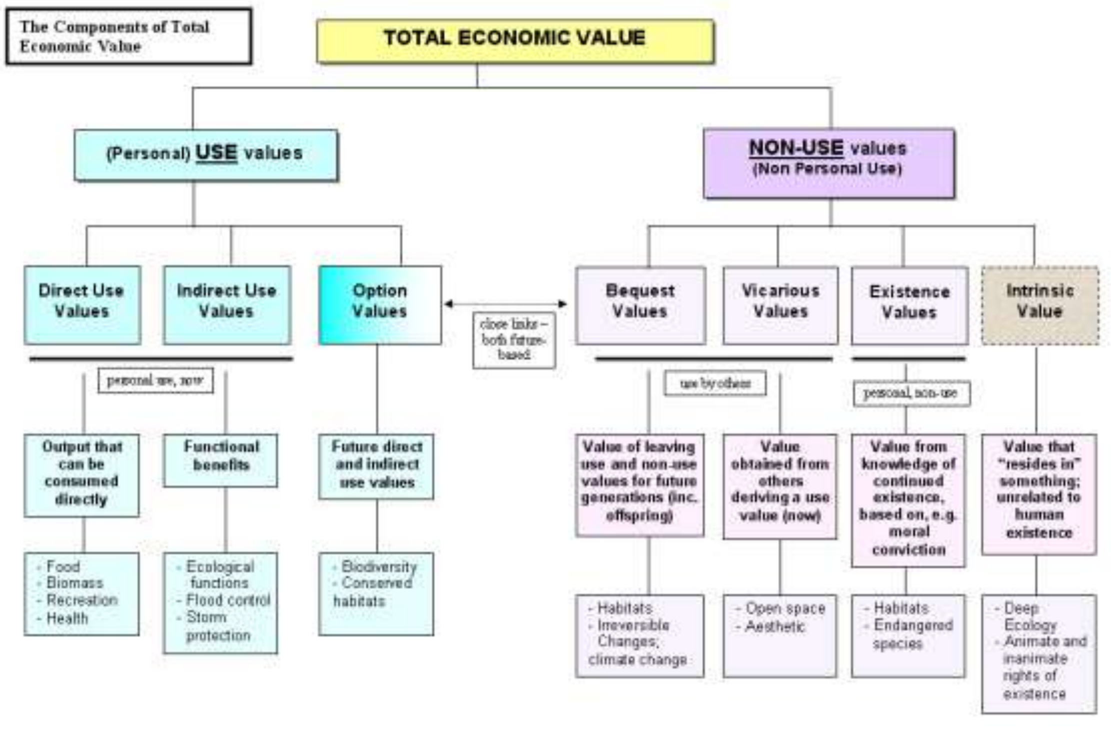


Figure 1: The total economic value approach to the assessment of human environmental impact.
Source: Adapted from Francis Gray Consulting Economist At Large (1996); Munasinghe, M. (1993); and Landell-Mills and Porras (2002, p14).

The externality categories utilised in the compendium are described in Table 1.

Table 1: 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.

2.2 The Identification of Major Externalities Associated with Alternate Water Options

In the "options by externality" analysis of Section 3, each study option has been analysed to identify its probable significant externality types and characteristics. The impacts of options are assessed both in general terms and across the various stages of their life cycle. Individual options, for example stormwater harvesting, do vary considerably in the actual technologies, processes, infrastructure and specific contextual mode of implementation and any application of the findings will need to be customised for specific settings. The externalities associated with each option were identified by surveying relevant existing research and findings in water-related studies and through technical analysis of the option characteristics and technologies.

In this second step of the analysis methodology, the externalities are presented for each option in two separate formats, though both tables are disaggregated in rows according to:

1. general features of the option (in the first row); and
2. specific life cycle phases of the option – typically collection, and sometimes storage, treatment, use and distribution, and decommissioning (in subsequent rows).

The first table format (for example, see Table 5 in Section 3) lists and briefly describes all identified externality effects for the option generally, and for each life cycle phase. The list of externalities is classified according to the externality type classification outlined earlier in this section (for example, GHG = greenhouse gas emissions; N = nutrients). The description also notes whether the externality tends to be a positive (+) or negative (-) externality; and if the effect predominantly occurs upstream (↑), downstream (↓) or in the localised area (◙) of the primary option location.

In the first table format, reference numbers are also shown to identify the relevant research or data sources for each externality. Full details of the sources cited can be found at the end of the report.

Box 2. The "OPTIONS x EXTERNALITY" MATRIX of Section 3.

The first part of the two major compendium results is the identification and short description of all significant externalities associated with each water servicing option. These "options x externality" matrices are broken into sections.

Each of the seven water service options is presented in separate tables. Within each table, the externalities have been allocated in accordance with the life-cycle stages in which they are likely to occur. They are also organised into the externality categories outlined in Table 1 above.

For every externality presented, 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 (◙).

For each water service option, two matrices are provided. The first is the extended version which outlines the nature of the externalities. The second version presents only the symbols and the reference source details.

2.3 Economic Value Estimates for Water-Related Externalities

Section 4 of this compendium presents detailed information about the relevant externalities and existing efforts to define their economic value and is intended to help guide externality analyses and valuation attempts across a wide range of applications and contexts. However, the focus impacts have been selected on the basis of their relevance for water options under consideration for SEQ.

Box 3. The "EXTERNALITY x VALUATION" MATRIX of Section 4.

In the second part of the compendium results, the "externality x valuation" tables provide details regarding the costing of the externality valued and its reference source, along 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 the previous section (e.g. energy valuations or amenity-related valuations).

Each of the valuations has been converted to $AUD 2010 based on historical exchange rates and Gross Domestic Product (GDP) implicit price deflators.

As discussed, it is important to incorporate both private (direct market) and external costs and benefits in water-related decision-making activities, as their neglect will encourage investment in sub-optimal alternatives which may prove regrettable in the long-run (Bryan and Kandulu, 2009). Failure to factor in externalities such as those identified in this compendium may lead to the misallocation of resources and increased levels of damage to society and the natural environment in which it is embedded (Rein, 1999).

Whilst it is commonly acknowledged that it is important to incorporate the externalities associated with water service options into decision making, there is significant controversy surrounding the extent to which monetary values for externalities should be used as a basis for policy (Gardner, Hatton MacDonald and Chung, 2006; Rein, 1999). Thus, this report presents the externalities and the relevant valuations separately, leaving it up to the individual practitioner as to whether they wish to take the next step of compiling and combining the externalities and valuations in the decision process. The externalities identified and/or the valuations can be applied as inputs and background information for a variety of decision-making frameworks, such as multiple criteria assessment or cost-benefit analysis.

As the foundation for subsequent economic assessment, the externality values are first assessed in "average" dollars per biophysical unit terms (for example, an economic cost of $100 per kg for nitrogen emissions from wastewater recycling). Per unit values can be sourced on a benefit or costing transfer basis (that is, from other relevant studies), or they can be calculated, with much more time and expense, from primary research or proxy data (based on the study area and context-specific characteristics). Estimates from transfer methods may also be adapted or adjusted on the basis of the unique features and conditions of the study context. Appropriate monetary unit value ranges, or median, modal or other measures of central tendency, would need to be identified for multiplication by total flow, production or other water service parameters.

The use of externality values must incorporate an understanding of the nature and weaknesses of the various valuation techniques adopted to generate monetary estimates of the costs and benefits associated with the "external" biophysical impacts of options analysed. Valuation techniques used tend to be related to the type of socio-economic impact, or natural resource benefit or use value, as depicted in the total economic value (TEV) concept and briefly discussed in the previous section.

For detailed information on environmental economic valuation techniques, see the Qld Department of Environment and Resource Management's (DERM) environmental management impact assessment web pages at: http://www.derm.qld.gov.au/environmental_management/impact_assessment/environmental_economics.html and the NSW Department of Environment, Climate Change and Water's *Envalue* database at http://www.environment.nsw.gov.au/envalueapp/.

Brief summaries of the range of techniques are provided in Table 2. In general, direct and indirect use values from the TEV scheme are often amenable to market-based valuation techniques where socioeconomic impacts can be directly linked to an existing, similar or related market. Changes in production or welfare attributed to the external effect can be assessed with prices (OECD, 2006). These techniques are called "revealed preference" approaches and draw largely upon existing and surrogate market data. Dose(exposure)-response models and estimates are often required to establish the quantitative link between natural environment flows or state changes (e.g. some water contamination measure) that society is exposed to and actual damage or well-being impacts upon humans and their economies (e.g. illness incidence) (United Nations, 2003).

Alternatively, non-use values (including existence, bequest, vicarious and most option values) are much more likely to be valued via stated preference or hypothetical market techniques such as contingent valuation or choice modelling. Direct uses from the TEV are commonly measured by specific economic techniques such as market analysis, change in production, hedonic pricing, travel cost analysis (TCA), replacement and restoration costs and, less frequently, contingent valuation (CV) (Turner *et al.*, 2000). Indirect uses can be valued using approaches based on damage costs: production functions; hedonic pricing; defensive expenditure; relocation, replacement and restoration costs; and contingent valuation. Hence, in the externality types covered in this report:

- Production impacts would tend to be assessed mainly with existing market techniques such as with change in production, and replacement and repair costs;
- Recreation impacts are typically assessed with travel cost analysis (TCA) and some existing market approaches; and
- Amenity effects are estimated with hedonic pricing, contingent valuation (CV) and TCA, and health impacts with cost-of-illness and human capital surrogate market techniques.

Ecosystem and biodiversity loss would also be suited to some production change and replacement cost approaches, but these values also share many non-use values that would require stated preference approaches such as CV and choice modelling.

Table 2: An Overview of Externality Valuation Techniques.

Technique	Application	Description	Constraints
1. Existing Market Techniques			
Change in productivity	Use Values. Used to value specific environmental goods or services, e.g. water quality.	Examines changes in the dollar value of outputs resulting from a change in the quality of an environmental good, e.g. loss of production from a fishery affected by water pollution.	Straightforward methodology with limited data requirements. However only applicable to certain goods and services.
Human capital (Change in income)	Used to value and environmental good or service, e.g. air quality.	Examines forgone earnings and cost of illness to value an environmental good, e.g. the impact on health of air pollution.	Hard to determine what damage is caused specifically by the good or service in question. Often subject to individual variability.
Preventative expenditure	Indirect Use Values (e.g. reducing pollution at the source through improved design of processes).	Examines expenditures made to prevent the effects of a fall in environmental quality, e.g. park management expenditure.	External circumstances may change the value of the original expected benefit and the method may therefore lead to under- or over-estimates. Also, preventative measures may be applicable to multiple sources simultaneously, making disaggregation to measure a specific source difficult.
Mitigation, repair and damage cost	Indirect Use Values (e.g. coastal protection and avoided erosion).	Uses estimates of the cost of repair or rehabilitation of environmental resources after environmental damage.	It is assumed that the cost of avoided damage or substitutes match the original benefit. But many external circumstances may change the value of the original expected benefit and the method may therefore lead to under- or overestimates.
Replacement cost	Indirect Use Values (e.g. coastal protection and avoided erosion).	Uses estimates of the cost of replacing the services of damaged productive assets, e.g. engineering works to prevent soil erosion after land clearing.	It is assumed that the cost of avoided damage or substitutes match the original benefit. But many external circumstances may change the value of the original expected benefit and the method may therefore lead to under- or overestimates. In addition, many fundamental ecosystem services (essential for life on Earth) may be unable to be adequately reflected in market units.
2. Surrogate Market Techniques			
Hedonic price	Some aspects of Indirect Use, Future Use and Non-Use Values.	Uses differences in prices of market goods (housing property prices, wages) to value an environmental good.	This method only captures people's willingness to pay for perceived benefits. If people are not aware of the link between the environment attribute and the benefits to themselves, the value will not be reflected in the price. This method is very data intensive.
Proxy good or Averting Behaviour	Use Values.	Uses value of a close market good substitute to value an environmental good. Also called 'averting behaviour', since this estimation technique infers a value for changes in spending on ways to reduce the impact of the lower environmental quality.	Hard to tell if the value of the marketed substitute actually reflected the characteristic in question. Often inadequate substitutes available for the use of this method.
Travel cost	Recreation and Amenity Values.	Uses cost of travelling to a certain environmental asset to impute its value (often used for national parks).	This method only gives an estimate. Overestimates are easily made as the site may not be the only reason for travelling to that area. This method also requires a lot of quantitative data.
3. Survey Methods – Stated Preference or Hypothetical Market Techniques			
Contingent valuation	Applicable to use and non-use values.	Uses survey methods to directly elicit a person's willingness to pay or to accept compensation for different qualities of an environmental good.	There are various sources of possible bias in the interview techniques. There is also controversy over whether people would actually pay the amounts stated in the interviews. It is the most controversial of the non-market valuation methods, but is one of the only ways to assign monetary values to non-use values of ecosystems that do not involve market purchases.
Choice modelling	Applicable to use values.	Choice modelling uses preferences for a set of scenarios to determine preferences for attributes of the environmental good being examined.	Potential bias sources. Expensive and time consuming to run.

Source: Adapted from Lambert (2003, pp.7-8).

3. WATER SERVICE OPTIONS IN THE STUDY – OVERVIEW AND EXTERNALITIES

The aim of this report is to first identify the primary externalities associated with alternative water management options, and then identify existing monetary value estimates of these externalities. This section of the report addresses the former, the identification of externalities. It does this by analysing each supply option to identify the social, environmental and economic impacts associated with the option in general and for each stage in its life cycle. These stages vary slightly for each option but, in general, they comprise the collection, storage, treatment, distribution of water and, finally, the decommissioning of the water supply option. The detailed descriptions of the impacts are provided to give background information for the summary of relevant externalities provided in the matrix. Both the descriptions of the options and their effects and the summary tables follow the same format – the identification of externalities in general terms, followed by a focus upon those linked to the various stages of its life cycle.

The water supply options that comprise the basis of this research are stormwater harvesting, desalination, dams, wastewater recycling, groundwater, greywater, and rainwater tanks. In practice, there is considerable variation for individual options. For example, stormwater harvesting will have different site specific technologies, processes, infrastructure and implementation and any application of material covered here will need to be customised for specific applications and settings.

The externalities associated with each option were identified by an extensive survey of relevant existing research and literature in water-related studies and through technical analysis of the option characteristics and technologies. The literature describing the externalities associated with each water supply option is vast and, at times, contradictory and hence this section of the report is principally intended to provide an overview of the externalities that must be considered in the externality evaluation process. It does not, however, provide definitive values for option impacts as externality impacts will invariably be site-specific.

Externalities can be classified in many different ways. This report aims to provide comprehensive background data with its analysis of the externalities associated with each option in order to ensure that important impacts will not be excluded and, hence, the compendium will be relevant for a range of contexts and locations. A subsequent project report (Water Externalities Report 2) will use some of the results from this compendium to cost the externalities relevant to the Logan-Albert test catchment. Given the study emphasis, the analysis of externalities in this report has concentrated on greenhouse gas 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 general water quality, and ecosystem and biodiversity changes and, as such, a more extensive range of externalities have been included in the tables in this report.

While these are primarily biophysical pressures or state changes, it also useful to consider the types of socioeconomic effects of such changes. For example, greenhouse gas emissions can have a broad range of actual costs and benefits upon society, ranging from changes in direct economic output, health, and loss or 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 groupings “checklist” for the options. These include costs and benefits on production, recreation, amenity, health, 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 production. The primary categories have been selected on the basis of their identified relevance and focus on existing research into water-related externalities (see Table 1).

The comprehensive identification of costs and benefits is important as the neglect of external effects is a major factor leading to the loss of natural ecosystems. Natural ecosystems fulfil functions and yield a range of services that are of substantial economic and cultural value to society. Ecosystem changes that are the result of the implementation of new water servicing options may lead to substantial economic and social impacts that are difficult or impossible to translate into monetary terms, such as the cultural value of a wetland. As a result, the value of ecosystem functions is not properly accounted for in conventional market economics, and the values of these functions are excluded from the economic decision-making process. This report acknowledges that the valuation of ecosystems and the consideration of development options is not a straightforward accounting exercise and not all ecosystem values can be expressed in economic terms (Bergkamp *et al.*, 2000, p.v).

3.1 Stormwater Harvesting

Stormwater harvesting has become more popular in urban Australia in recent years due to its ability to both reduce pollution from stormwater runoff and provide a valuable water supply source (Hatt, Deletic and Fletcher, 2006; Mitchell *et al.*, 2007). 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). Stormwater has high pollutant loading and is a major cause of environmental degradation of urban waterways and adjacent coastal waters (PMSEIC, 2003, p. 4; Naji and Lustig, 2006, p.196). 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 use of this resource (Mitchell *et al.*, 2007, p.135). 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).

The volume of stormwater runoff from urban areas in SEQ is large enough 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, recreation areas and sporting grounds. The Queensland Government has undertaken more detailed research to assess opportunities for stormwater harvesting in SEQ (QWC, 2009).

3.1.1 Biophysical Description of Stormwater Harvesting

Stormwater harvesting differs considerably between projects, but generally involves common elements of: collection of stormwater from drains, creeks or ponds; temporary storage in small dams or tanks; treatment to remove contaminants; and finally distribution to users (Connell Wagner, 2008; Mitchell *et al.*, 2007, p.136; Fletcher, Deletic and Hatt, 2004).

Figure 2 below demonstrates the stormwater harvesting process from collection through to distribution, where it may re-enter the stormwater harvesting cycle or become part of the hydrologic cycle through evaporation, runoff into rivers and seepage into groundwater.

The collection of stormwater involves the transportation of runoff through urban drainage systems such as traditional curb and channel, or more recently through WSUD technology such as grass swale and strip and porous pavements, infiltration trenches or biofilters. These techniques vary depending on catchment size, land use within the catchment and rainfall, as well as financial and land availability constraints.

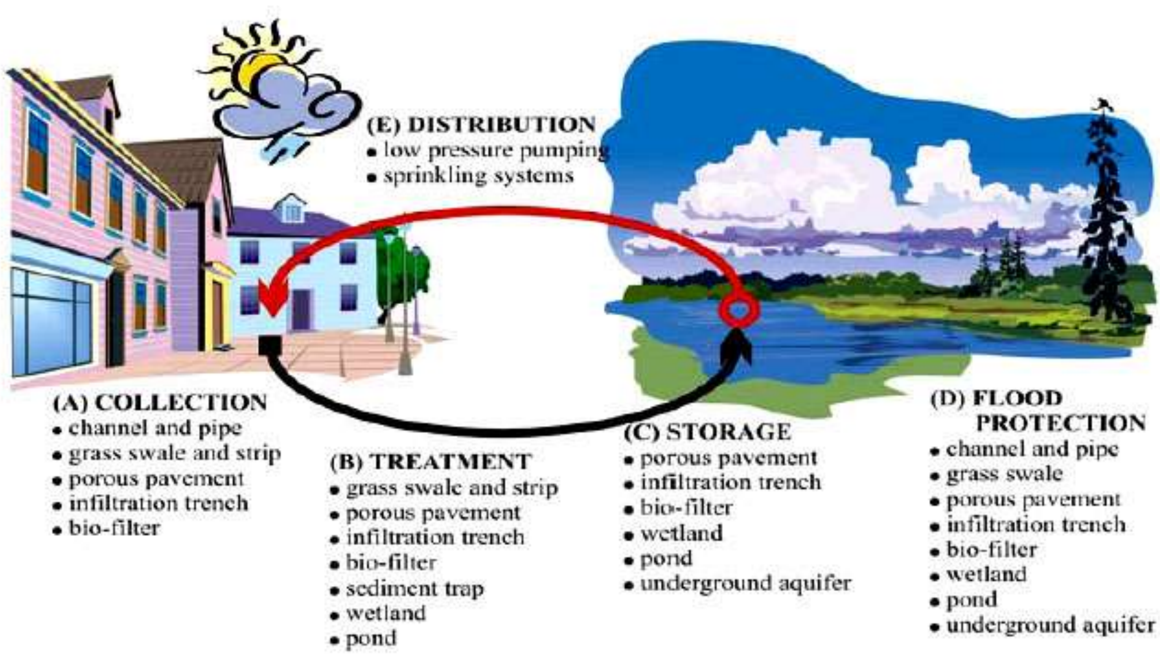


Figure 2: The various stages and main features of stormwater harvesting and treatment.

Source: Fletcher, Deletic and Hatt, (2004, p.22).

As stormwater comprises runoff from roads, driveways, residential gardens, parks etc., stormwater contains a number of contaminants including those listed in Table 3.

Table 3: Common contaminants found in stormwater.

Sediments (suspended solids)	The result of soil erosion, particularly from construction sites where poor management practices are observed. Sediment washoff can also be from ash, dust and other atmospheric fall-out.
Nutrients	Primarily nitrogen and phosphorus, nutrients can contribute to excessive plant and algal growth. Typical sources are fertilisers, animal faeces, detergents, sewer overflows, septic tank and sewer seepage, and soil erosion.
Gross Pollutants and Litter	Includes natural leaf litter/vegetation and man-made litter material such as litter, plastics, glass, metal, and paper.
Heavy Metals	Lead (Pb), zinc (Zn), cadmium (Cd), chromium (Cr), and nickel (Ni) are toxic to humans and animals and can be present in urban stormwater runoff. Sources of heavy metals in stormwater including vehicle emissions, wear down of brakes, tyres, and other vehicle components, metal roofs and industrial emissions.
Toxic Organics	These generally derive from chemical use within urban catchments, typically agricultural, garden and household chemicals including pesticides and herbicides.
Pathogenic micro-organisms	These present perhaps the primary public health concern related to stormwater harvesting and reuse. These include viruses, bacteria and protozoa and may originate from soils, animal droppings and sewerage system leakage and overflows.
Hydrocarbons	Typically derived from vehicles and machinery, spills, natural vegetation leachate, food processing and detergents. In large concentrations, hydrocarbons can cause toxicity, and detergent surfactants will break down the cell walls of animals and plants.

Source: Hausler (2006, p11).

Stormwater is then directed from the drainage system into sediment traps, wetlands, ponds, tanks or underground aquifers that provide storage, treatment and flood control functions. Treatment is provided through the natural biochemical processes. For example, in wetlands these include the process of settling, ultraviolet radiation (UV) disinfection, filtration, adsorption, ion exchange, biological digestion and denitrification (Johengen and LaRock, 1993, p.348). Depending on the end use of the water, some stormwater may also require further treatment such as micro-filtration or reverse osmosis and disinfection using chlorination or UV radiation.

Following storage and treatment, stormwater is pumped or distributed for irrigation, industrial use, external residential use or toilet flushing. Applications depend on water quality parameters set by the regulatory authority and the risks associated with the particular end use, for example treated stormwater can be reused for restricted or unrestricted irrigation of agricultural crops depending on its quality (Hausler, 2006). Stormwater can also be reused for flushing toilets, for cleaning purposes, as cooling water and as a reliable water supply for natural wetlands or nature reserve areas. Constructed wetlands can also serve as infiltration areas for groundwater replenishment (Connell Wagner, 2008).

3.1.2 Impacts

General Impacts

The primary externalities associated with the urban drainage systems designed to protect of cities from flooding and the transmission of waterborne diseases (Nanbakhsh, 2005, p.169) relate to impacts on receiving streams, rivers and oceans (Mitchell *et al.*, 2007, p.135). Stormwater is 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, p.14; Brown, 2005).

Increasingly however, stormwater is being viewed as a valuable water resource. To reduce the environmental impacts, wetlands are being constructed in a number of Australian cities to exploit the biogeochemical cycles that naturally occur in wetland eco-systems for the purpose of wastewater treatment prior to release into the waterways or reuse (Rousseau *et al.*, 2008, p.181). As well as treatment wetlands, other WSUD options such as unsealed swales and urban lakes hold water back in the landscape, reducing velocities so that the damaging pulses of stormwater are reduced (PMSEIC, 2003, p.4; Fletcher *et al.*, 2004; WSAA, 2006).

In addition to reducing pollution, stormwater harvesting is able to off-set potable water consumption. A recent study found that 60 percent of residential water could be supplemented, equating to close to 100 percent of the total stormwater runoff from the site (Coombes, Argue and Kuczera, 2000). However, stormwater is rainfall dependent and therefore subject to seasonal and climatic variation and is also proving increasingly unreliable due to climate change (Environmental Protection and Heritage Council, 2007). 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 both environmental flow enhancement as well as a substitute for potable water supply (Mitchell *et al.*, 2007, p.142; WSAA, 2006; Environment Australia, 2002). However, the use of stormwater reduces drainage and detention requirements downstream and relieves pressure on drainage infrastructure during storm events (Taylor, 2005; Brown, 2005; Naji and Lustig, 2006).

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 harvesting projects. Of the 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 were demonstrated to be of educational value (Hatt, Deletic and Fletcher, 2006, p.105).

Table 4 gives a summary of the stormwater management objectives from the study. The centre also developed guidelines for the costing of externalities associated with stormwater harvesting, using a conceptual model that shows costs and benefits spatially represented around the stormwater harvesting system (see Figure 3) (Taylor, 2005, p.8).

Figure 3 shows the key externalities of the system, including those represented by property values around the constructed site, as well as those associated with life-cycles, management, and downstream benefits such as improved water quality (Taylor, 2005).

Table 4: Management objectives of the studied stormwater recycling schemes.

Site	Objectives							
	Water conservation	Protection/ improvement of downstream waters	Flood manage ment	Enhance ecological value of site and/or downstream	Visual amenity/ recreation value	Education opportunity	Demonstrate innovative water management	Demonstrate cost- effective stormwater management
Altona Green Park	✓				✓			
Bobbin Head Road	✓	✓	✓	✓				
Bowies Flat Wetland,		✓		✓	✓	✓		
CSU Thurgoona	✓						✓	
Figtree Place	✓		✓				✓	
Hawkesbury	✓					✓	✓	
Homebush Bay	✓	✓					✓	
Inkerman Oasis							✓	✓
Kogarah Town Square	✓	✓	✓		✓			
Manly STAR	✓	✓	✓				✓	✓
Oaklands Park							✓	✓
Parafield/Mi chell Project	✓	✓	✓	✓	✓		✓	
Parfitt Square	✓	✓	✓		✓			
Powells Creek				✓	✓		✓	✓
Santa Monica		✓			✓	✓		✓
Solander Park		✓				✓	✓	
Taronga Zoo	✓	✓					✓	

Source: Hatt, Deletic and Fletcher (2006, p.105).

Collection Impacts

There are 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 a treatment function. 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 reducing storage maintenance requirements (Nanbakhsh, 2005; WSAA, 2006).

The negative externalities associated with the above-mentioned measures for collecting stormwater are: the maintenance requirements may be a high cost for councils or a burden on local residents; some collection and treatment systems may impact on the availability of local street parking as they require extra area and access adjacent to the curb; there are also exfiltration and evaporation losses associated with the incorporation of swales and biofilters into the collection system. These losses have been shown to be minimal (Taylor, 2005).

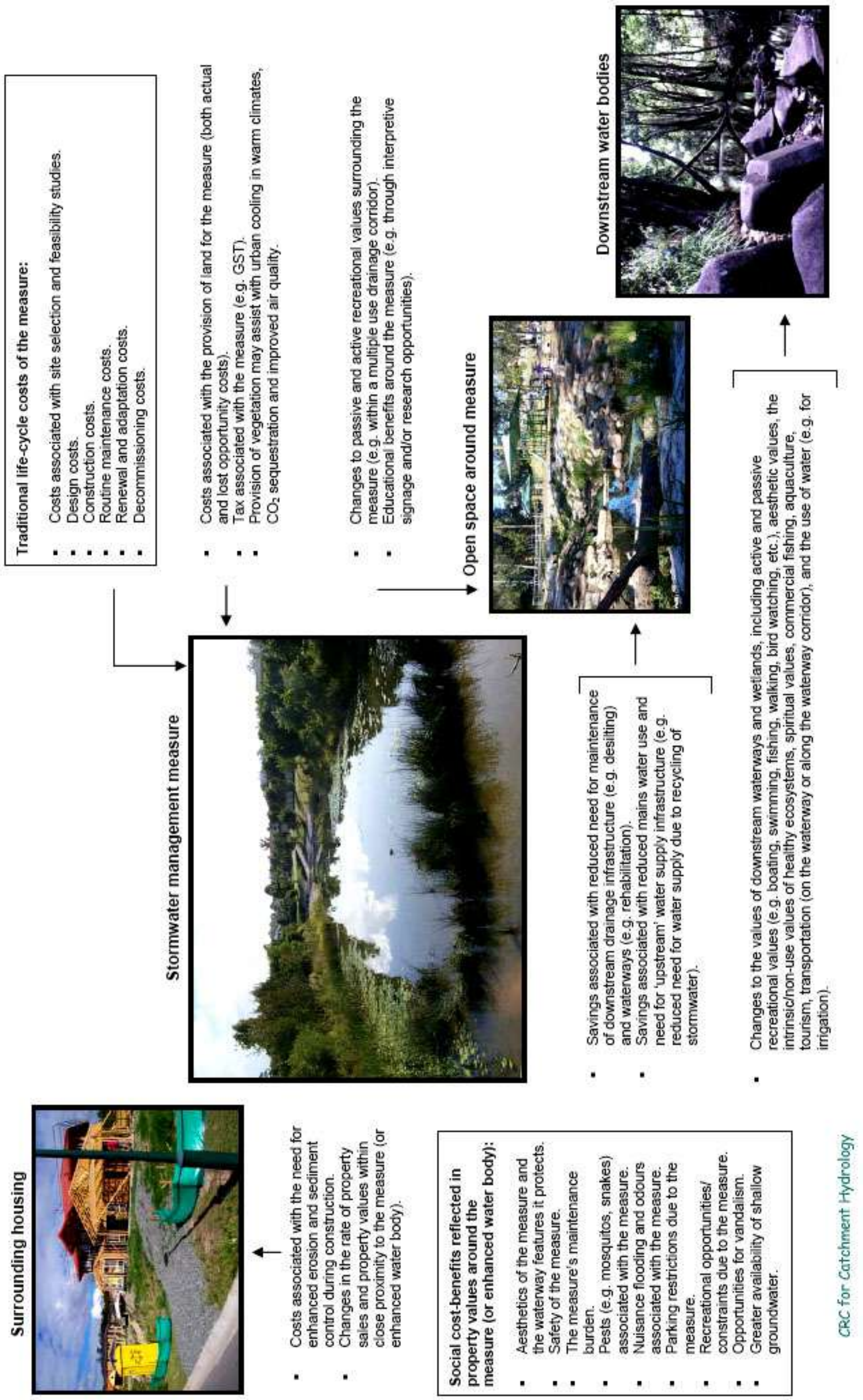


Figure 3: Potential costs and benefits surrounding structural urban stormwater management measures to improve waterway health.
Source: Taylor (2005, p.C-11).

Treatment Impacts

The most common method for the treatment of stormwater is to use a natural, constructed, or restored wetland (Rousseau *et al.*, 2008 - p181; Barten, 1986 in Johengen and LaRock, 1993 - p348). A key externality of stormwater harvesting is the use of the inherent treatment properties of wetlands to improve the 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 - p348).

While there are considerable benefits of using natural processes for stormwater treatment, there are some concerns regarding the 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 - p183). 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 - p183; Nanbakhsh, 2005 - p169). Wetlands are also highly effective in removing pathogenic organisms and low-concentration compounds such as pharmaceuticals, personal care products and heavy metals (Rousseau *et al.*, 2008 - p184).

The results for nitrogen removal within constructed wetlands designed to treat urban stormwater runoff have been less consistent. A study by the UNESCO Institute of Water Studies in 2008 that quantified the nutrient removal process found the nitrogen removal efficiency of wetlands was strongly correlated to the uptake processes taking place within the substrate, macrophytes, and periphytic communities (Kouki *et al.*, 2009 - p452). Nitrogen removal efficiency varied substantially throughout the seasons, which may be due to additional sources of nutrients that had built up in the treatment facility, or from decomposition of plant matter (Johengen and LaRock, 1993 - p364). Another study of the nitrogen removal process of wetlands, by the Urmia University of Medical Sciences in Iran, found that the denitrification process was not completed, resulting in higher nitrate and nitrogen concentrations in the outflows than inflows (Nanbakhsh, 2005 - p169).

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, site inspection, effluent sampling, cleaning, weed control and plant harvesting. If wetlands are well maintained they can meet the high standards required for use in irrigating parks and gardens (Rousseau *et al.*, 2008 - p181).

Storage Impacts

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. These externalities are discussed in detail below:

Flood Protection

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 storages have the potential to be designed to provide both flood protection and stormwater storage for harvesting, whereas offline stormwater storages do not provide flood protection. The design of a storage for both supply and flood protection requires careful consideration of the likely level of the active storage portion as this will influence flood mitigation behaviour (Mitchell *et al.*, 2007; Brown, 2005).

Social Benefits

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). 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.

Wetlands may also increase surrounding property values and rates of sale, based on their aesthetic values (Taylor, 2005). Property values may be increased if the property has a direct view of a constructed wetland or through the potential recreational benefits provided for people living in close proximity (Taylor, 2005 - p18). 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 - p187). 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.*, 1999 in Coombes *et al.*, 2002; Coombes, Argue and Kuczera, 2000).

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 of those houses overlooking the area. Figure 4 presents a conceptual diagram of benefits from wetlands in relation to property value.

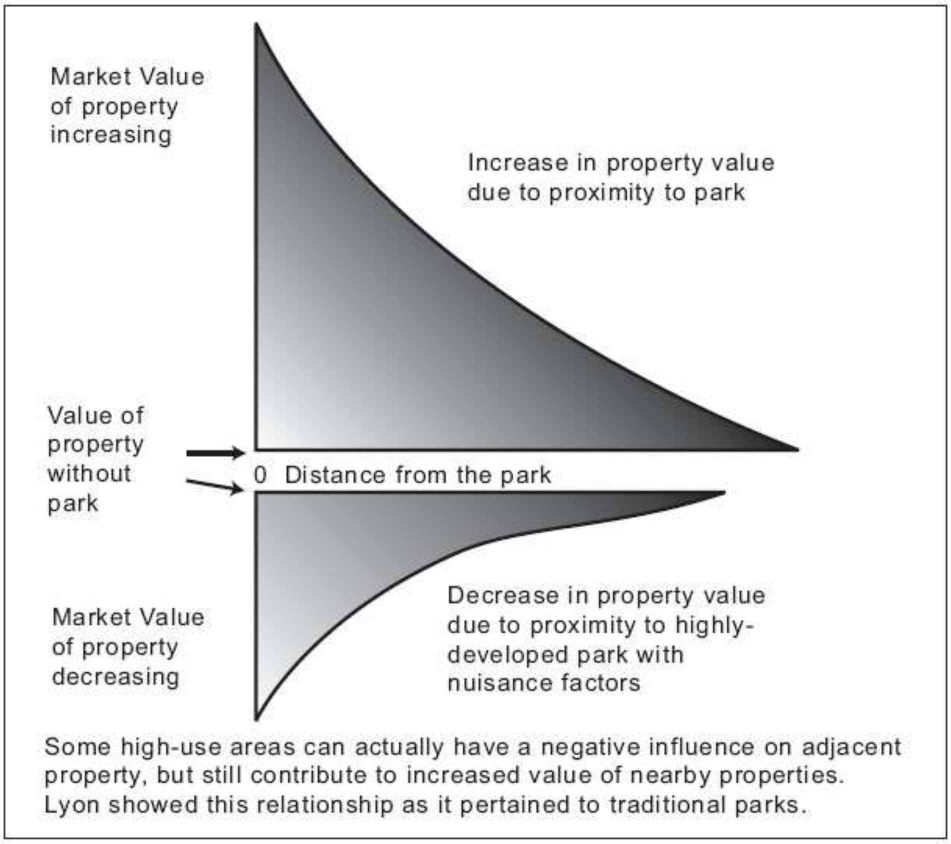


Figure 4: Conceptual relationship between property values and proximity to open space/parks (with or without water bodies).

Source: Taylor (200 5, p.C-31).

Water Quality and Productivity

Whilst the high loading of nutrients in stormwater runoff may cause anaerobic conditions to develop in storage areas, opportunities for the beneficial use of those nutrients can also arise (Rousseau *et al.*, 2008 - p185). 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 - p182). 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 (Rousseau *et al.*, 2008 - p185).

Biodiversity / Eco-Systems

Constructed wetlands provide certain ancillary benefits for the provision of a wildlife habitat, not only for enjoyment by people, but also encompass bequest biodiversity and ecosystem values (Rousseau *et al.*, 2008). Wetlands are home to mammals, birds, amphibians, reptiles, fish and invertebrates. 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 - p183).

In addition to the non-use values associated with a healthy ecosystem, wetlands provide a number of ecosystem services that relate to direct benefits, such as water regulation, water supply, waste treatment, food production and recreation. Vegetation also provides shading, habitat, and improvements in air quality, urban cooling and aesthetics (Taylor, 2005 - p23).

Health

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 siting 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; and vegetation thinning which 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 - p185).

Another health risk that is less likely to occur than mosquito related diseases, but also has severe consequences, is that wetlands and urban lakes and ponds pose a drowning risk. Their proximity to roads also increases the likelihood of cars entering the area due to accidents (Taylor, 2005).

Use/Distribution Impacts

The externalities that need to be included in 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 a conventional storage. Providing non-potable harvested stormwater for urban irrigation and toilet flushing through dual reticulation can be implemented in 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 inhibiting, as the financial costs of rainwater tanks also outweigh the financial benefits.

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. The aquifer provides an additional treatment. The process of aquifer storage and recovery (ASR) is described in Figure 5.

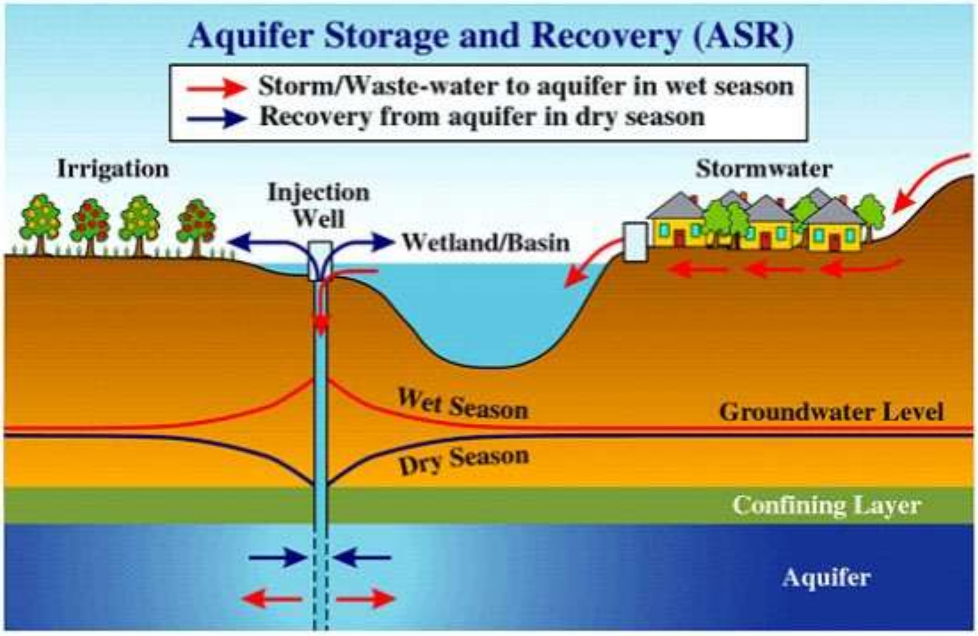


Figure 5: The process of aquifer storage and recovery (ASR).
Source: CSIRO (2008, web page)

Treatment of the runoff is necessary prior to aquifer storage as irreversible damage can occur to the aquifer. An ASR scheme should not lead to deterioration of the water quality from an aquifer. The injected water should be of Class A+ standard. Controls are needed to ensure entrained air and organic matter in the recharged water are minimised to avoid algal growth (Hausler, 2006).

Decommissioning Impacts

Due to the natural forms and low use of machinery and plant, harvesting measures are assumed to have an infinite lifespan if well maintained (Mitchell *et al.*, 2006).

3.1.3 The Externality Tables for Stormwater Harvesting

The complete listing and short descriptions of the major characteristics of the stormwater harvesting externalities are presented in the tables below. The information is provided in two table formats. The first (Table 5) is intended as a summary table and is a condensed version showing some key features in symbolic form (see the table key and paragraph below) and the reference source codes. The second version (Table 6) comprises the extended version with some detail about the nature of the externalities as examined in existing research.

As described in the methodology section, in both tables (and in similar tables in following sections), the externalities 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. greenhouse gas emissions (GHGs)). 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 (◙).

Table 5: Main externalities associated with stormwater harvesting - Summary table.

Note: positive (+) or negative externality (-); whether impacts tend to occur predominantly downstream (↓), upstream (↑), or within the immediate surrounds of the supply infrastructure (◙). Reference label numbers are provided at the end of each externality listed. The full reference details are provided in Appendix A.

STORMWATER HARVESTING												
LIFE CYCLE OR OPERATIONAL PHASE	**EXTERNALITY TYPE (showing if positive or negative effect, main location and reference source number)** *(see Appendix A for reference source code details)*											
	Greenhouse Gas Emissions	**Energy**	**Water Quality**	**Nutrients**	**Production**	**Recreation**	**Amenity**	**Health**	**Ecosystem**	**Biodiversity**	**Non-use Values**[1]	**Other** (eg. flood mitigation)
General	+, ◙ 95		+,↓, ◙ 46, 89, 155, 95	+,↓ 87	+,-,↓ 89, 271,95, 273	+, ◙, ↓ 46, 263, 46, 271	+, ↓, ◙ 273, 263, 46, 271		+, ↓, ◙ 273, 46, 89, 271, 95, 249, 272, 155, 145, 277		+, ↓, ↑, ◙ 95	+, ↓, ◙ 89
Collection				+, ↓ 88,155, 87	-,◙ 95	+, ↑, ↓, ◙ 95			+, -, ↓, ◙ 55, 145, 95, 273			+, -, ◙ 95, 89, 277
Treatment	+ 95		+,↓, ◙ 263, 46	+,↓, ◙ 265					-, ↓, ◙ 272			-, ◙ 155, 272
Storage					-, +, ◙ 263, 277, 95	+,↓, ◙ 46, 95	+, -, ◙,↓ 95, 263, 89, 155	-, ◙ 263, 90, 99, 95, 277		+, ◙ 263, 275		-, +, ↓, ◙ 95, 46, 272
Use/Distribution					+,↓, ◙ 33				- , ↓, ◙ 274			
Decommissioning												+ 94

1. Non-use values include option, bequest, intrinsic, vicarious and existence values in the total economic value (TEV) scheme.

Table 6: Main externalities associated with stormwater harvesting – Existing study details.

Note: positive (+) or negative externality (-); whether impacts tend to occur predominantly downstream (↓), upstream (↑), or within the immediate surrounds of the supply infrastructure (◙). Reference label numbers are provided at the end of each externality listed. The full reference details are provided in Appendix A.

STORMWATER HARVESTING	
LIFE CYCLE OR OPERATIONAL PHASE	**EXTERNALITY TYPE, DESCRIPTION (showing if positive or negative effect, main location and reference source number)** *(see Appendix A for reference source code details)*
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 (see inset table to left for externality type codes):** Carbon sequestration derived from the application of vegetated treatment measures (+) 95 *(= reference source code)* **WQ:** Reduction in pollution from stormwater runoff and improved flow regime (+, ↓) 46, 89 **WQ:** Increases in availability of shallow groundwater (+, ↓, ◙) 95 **WQ:** Protects the water quality of the surface, ground and marine waters relative to pre-development conditions (+, ↓, ◙) 155, 274 **N:** Potential to reduce nutrient build up, e.g. phosphorus and nitrogen through filtration, adsorption, ion exchange, biological assimilation, and denitrification (+, ↓) 87 **P:** Can assist in flood mitigation (+, ↓) 89, 271 **P:** Commercial fishing and aquaculture is affected by receiving waters (+, ↓) 95 **P:** Reduced need for detention infrastructure downstream and decreased need for drainage infrastructure maintenance (-, ↓) 95, 271 **P, A, E:** Reductions in the processes leading to the acidification of coastal catchments (+, ↓) 273 **R:** Increased potential for tourism and water-based transport in affected receiving waters (+, ◙, ↓) 95 **R and A:** Potential to provide recreational spaces, i.e. if opt for urban wetland/pond storage systems. (+, ◙) 263, 46, 271 **E:** Potential to enhance ecological value downstream, reduction in contaminants and improved flow regimes etc (+, ↓) 46, 89, 271 **E:** Air quality improvements (+, ◙) 95 **E:** reduced pollutant loads to receiving waters (+, ◙, ↓) 272 **E:** Reduced potable water use (+, ◙, ↓) 272 **E:** Reduced Impact of acid sulphate soils (+, ◙) 273 **E:** Minimise the impact upon existing natural features and the hydrologic behaviours of catchments (+) 155, 145 **E:** Reductions in waterway erosion and pollution and the lessening of risk of the acidification of soils (+, ◙, ↓) 273 **NU:** Intrinsic and spiritual value of healthy waterways (esp. aquatic and riparian ecosystems) AND value of having un-restricted future access to land that stormwater infrastructure occupies AND value of maintaining healthy waterways for future generations (+, ↓, ↑, ◙) 95 **O:** Can assist in flood mitigation (+, ↓, ◙) 89
Collection	**N**: Ability to reduce suspended solids and pollutants from road runoff (+, ↓) 88, 155 **N:** Potential to reduce nutrient build up, e.g. phosphorus and nitrogen through filtration, adsorption, ion exchange, biological assimilation, and denitrification (+, ↓) 87 **P**: Maintenance can be burden on residents (e.g. maintaining roadside swales) (-,◙) 95 **R:** provision of transport opportunities along waterways and drainage corridors (+, ↑, ↓, ◙) 95 **E:** Minimises the impact upon existing natural features ad the hydrologic behaviours of catchments (+) 155, 145 **E**: Decreased erosion (+,↓) 95, 273 **E:** Reductions in litter pollution into waterways (+,↓) 273 **E:** Can interrupt environmental flows to urban rivers and creeks, denying stormwater flows if over-extraction occurs (-, ↓, ◙) 155, 273 **O:** Parking restrictions around stormwater measure (e.g. keeping off roadside swales) (-,◙) 95 **O:** Can assist in flood mitigation (+, ↓, ◙) 89 **O:** Reliant on rainfall which is increasingly unreliable and subject to seasonal and climatic variation - water security implications as supply option (-, ↓, ◙) 277
Treatment	**GHG:** CO_2 sequestration. (+) 95 **WQ**: Ability to remove some pathogens, and improve/stabilise nutrient levels (+,↓, ◙) 263 **WQ:** Increases water quality downstream (+, ↓) 46 **N**: abatement of nitrogen pollution (+,↓, ◙) 265 **E:** Disposal of the waste from the treatment plant may be an issue depending on the location of the plant (-, ↓, ◙) 272 **O:** Stormwater is often of poor quality due to flushed pollutant from roads etc and therefore requires high levels of treatment which is expensive (-,◙) 155, 272
Storage	**P:** Evapo-transpiration on large scale may lead to increased salinity rendering water unusable for irrigation (-) 263 **P and H:** May be subject to intentional sabotage (-,◙) 277 **P and R:** Education and research asset in form of constructed wetland or pond (+, ◙) 95 **R**: Provides recreational spaces (e.g. swimming and boating) (+) 46, 95 **R:** Improved recreational fishing opportunities (+, ↓) 95 **A**: Increases to surrounding property values and rates of sale by aesthetic value of stormwater ponds/wetlands (+, ◙) 95 **A**: May cause odour nuisance in high loaded systems with anaerobic conditions (-, ◙) 263 **A:** Can provide aesthetic appeal if well designed (e.g. urban wetland/pond systems) and increase capacity for use on aesthetic spaces (parks etc) (+, ◙, ↓) 89, 95, 155 **H**: May provide potential mosquito (disease vectors) breeding sites if poorly designed and maintained (-, ◙) 263, 90, 99 **H:** Drowning hazard (-, ◙) 95 **H and O:** flooding around stormwater retention measures (-, ◙) 95 **B:** Provision of habitat for native flora and fauna (+, ◙) 263, 275 **O**: Potential to assist in flood management (+, ↓) 46 **O:** Storages require substantial areas of land, which are often not available in established urban areas (-,◙) 272
Use/Distribution	**P:** Recycling rainwater/stormwater achieves the water reduction objective as well as potentially relieving the drainage infrastructure especially in minor storm events. (+,↓, ◙) 33 **P:** Additionally, a well targeted recycling system could also reduce the peak flow design criteria for mains water and sewerage sizing, thus reducing headwork charges for new developments.(+,↓) 33 **E:** excessive harvesting of stormwater could also be detrimental to stream health (-, ↓) 274 **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 (-) (Porter, 2009)
Decommissioning	**O:** Assumed to have infinite lifespan if well maintained (+) 94

3.2 Desalination

Desalination is a water supply option gaining popularity across the globe, accounting for worldwide water production of 24.5 million m^3 per day in 2006 (Lattemann and Höpner, 2008, p.2). Its widespread popularity is due to its ability to provide a rainfall independent, constant but flexible and virtually unlimited (given energy and infrastructure capacity) supply of fresh water (Lattemann and Höpner, 2008, p.2). However, desalination also comes with a variety of potential adverse "external" impacts. Many of the latent external costs are associated with the discharge of hyper-saline water or "brine" into marine environments and the high energy consumption of the desalination treatment process.

The severity of external impacts, especially those associated with brine and energy use, depends upon:

1. the specific characteristics of the natural environment where it is located, given variation in natural hydrological processes and sensitivity of different ecosystems to the impacts of saline discharges (Einav, Harussi and Perry, 2002; Abdul Aziz *et al.*, 2000), and
2. the specific plant process technologies, design and primary energy sources; operational characteristics, and water quality and other environmental and technical management plans deployed.

Table 7 gives a brief overview of the major social costs and benefits typically associated with water supply options based on desalination.

Table 7: Summary of major potential social costs and benefits of desalination plants.

Category	Impact
Positive effects	
Reliability of supply and water security	Climate independence
Diversification and reduced risk of combined system failure	Prevention of major regional water crises; reduction in adverse environmental and other effects of extreme use of other supply sources (e.g. dams)
Constant but flexible supply	Maintain regional system water balance
Water quality	Likely improvements in water quality and sanitation with desalinated water which tends to be is free from pollutants, carcinogens, viruses and offending tastes and colours. Water is also softened in the process preventing the formation of limescale and clogging on pipes and appliances and reducing the need for anti-scaling products and long term wear and tear to pipe infrastructure.
Negative effects (mainly externalities)	
Brine emissions to the ocean or land – hyper-saline water and potential chemical emissions such as antiscalants and washing solutions; also temperature impacts for thermal processes	Brine discharge can adversely affect marine life
Relatively intensive energy use and increased demand and dependence on energy: Greenhouse gas (GHG) emissions if based on fossil fuel sources to generate power for desalination plants	Energy costs and security, externalities associated with various primary energy sources and processing; for GHGs, climate change, human health, agricultural productivity, biodiversity, many other impacts associated with climate change and sea level rises
Land use: Impact related to the loss of the open seashore for construction of desalination plants; pipeline corridor impacts	Land degradation and soil contamination, biodiversity, marine and other ecosystem stress, scarcity of coastal sites
Other	Long lead times into operation; noise pollution

Source: Extended from Al-Agha and Mortaja (2005).

Desalination is predicted to play an increasingly important role in water supply provision in Australia. The National Water Commission in its 'Review of Emerging Trends in Desalination 2008' predicted that, by 2013, a total of approximately 460 gigalitres of drinking water will be produced per year from desalination plants operating in Melbourne, Sydney, Perth, Adelaide and parts of SEQ (NWC, 2008).

The Tugun desalination plant on the Gold Coast in SEQ was expected to supply 125 ML/day of fresh water into the water supply system if required (QWC, 2009).

In the 2009 *South East Queensland Water Strategy*, the reliability of desalination sources is recognised and they are the preferred option to ensure future demands could be met in the SEQ region and the “only practical supply to fill the supply gap” (QWC, 2009, p.109). The Queensland Government identified Lytton and Marcoola on the Sunshine Coast as priority sites, with Bribie Island and a second plant at Tugun as long-term reserve sites. Environmental impact issues were recognised as needing to be addressed at each site via environmental impact assessment and community impact planning. The Kawana Waters and North and South Stradbroke Island sites have been excluded from any further consideration for environmental reasons (QWC, 2009). The 2009 *SEQ Water Strategy* notes that desalination may provide 8% of the SEQ water grid supply by 2012.

An increasing reliance on desalination to ensure water supply security in the SEQ region will increase the energy requirements of the regional water supply system. Under such conditions, it was estimated that the total energy required to operate the SEQ Water Grid could increase threefold from 0.5 megawatt hours per megalitre in 2010 to 1.6 megawatt hours per megalitre in 2050 (QWC, 2009, p.5).

3.2.1 Biophysical Description of Desalination

Desalination involves removing the salt from seawater (or brackish groundwater) to make it useable for a range of purposes, including drinking. Seawater is drawn through a tunnel from an offshore intake and then pumped to the treatment plant. The first treatment stage is the removal of suspended solids. The second stage is desalination of the feed-water by thermal distillation or membrane technology. Reverse osmosis (RO) is the most common membrane technology and is used in the Tugun desalination plant in SEQ. RO involves filtering the water through membranes under very high pressure to remove salts and other impurities.

The third stage of treatment is ‘potabilisation’ (i.e. making the water potable) and stabilisation. This occurs through the addition of chemicals and is followed by disinfection. The purified water is then transported for blending in existing water storages or into the water distribution system. The concentrated brine which remains is returned to the ocean via another tunnel parallel to the intake. The brine is released from multiple diffusers spread along the sea floor. Figure 6 depicts the desalination process used at the Tugun desalination plant in SEQ.

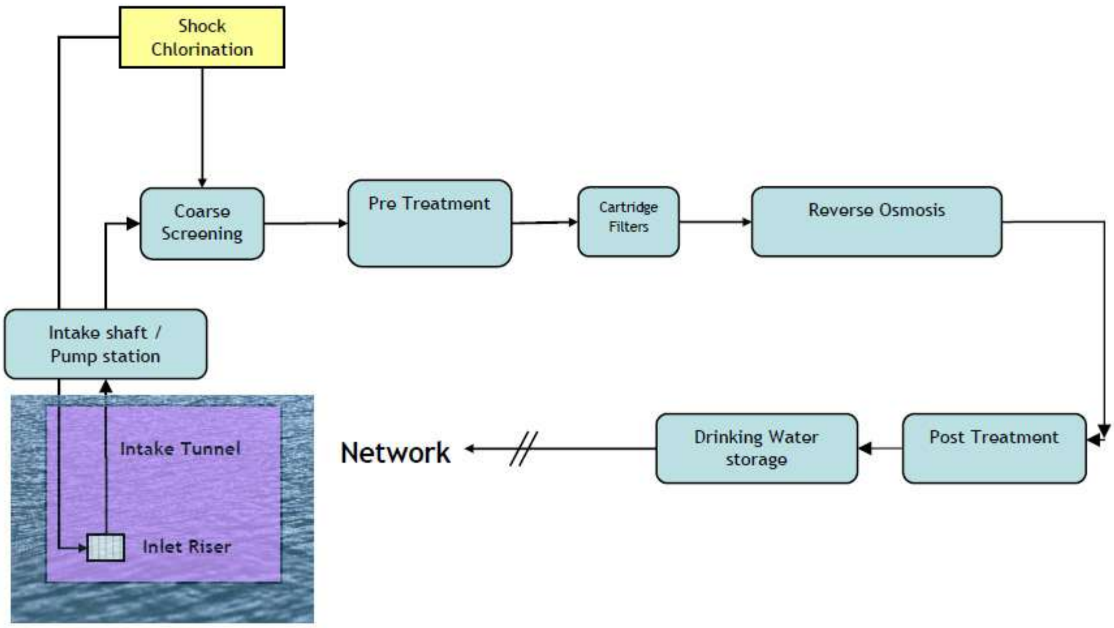


Figure 6: Tugun treatment plant process.
Source: Adapted from Bellizia (2008, p.131)

3.2.2 Impacts

A. General Impacts

Although the bulk of the following discussion relates to potential negative externalities linked to desalinated water supplies, it is important to emphasise that there are several significant social benefits associated with this option. In addition to advantages such as reliability of supply and ability to control water production output to ensure water balance (see Table 7), there are also external benefits (or positive externalities) associated with desalination. These include a likely improvement in water quality and sanitation as the water derived from desalination is generally free from pollutants, carcinogens, viruses and offending tastes and colours (Einav, Harussi and Perry, 2002). Water is also softened in the process, thus preventing the formation of lime scale and clogging on pipes and appliances. This reduces the need for anti-scaling products and long term wear and tear to pipe infrastructure. Desalination can also have the benefit of off-setting mains water supplied from dams and reducing detrimental ecosystem impacts from excessive extraction from such in-stream surface water supplies (Cohen, Wolff and Nelson, 2004).

As discussed, the extent of external costs accompanying desalination is highly contingent upon a range of factors such as location, technology and energy sources, management and regulatory practices, and operational characteristics. Two of the main possible adverse impact domains are related to brine emissions and relatively intensive energy use, and these aspects occupy much of the following overview. However, the analysis is presented as a generalised assessment of potential effects to be considered with desalination supply sources and is not based on specific features of the existing Tugun facility or other desalination plants that may be built in SEQ. For example, water temperature issues would not apply to the RO technology used at Tugun and pH and dissolved oxygen drawdown effects would also be less relevant than for distillation methods. Furthermore, the implementation of careful and appropriate siting, operation, management practices and technologies can prevent or minimise many of the suite of impacts considered and hence ensure acceptable environmental quality and other social and economic criteria are achieved.

Variation in natural processes of dispersion and dilution and the ecological sensitivity and urbanisation features in the surrounding environment will lead to significant differences in impact levels. Although further monitoring and research is in progress, evidence for the RO desalination plant in Cockburn Sound near Perth (operational since 2006) suggests the ambient salinity and dissolved oxygen levels have not been radically affected by brine emissions and impacts upon marine species and ecosystems (and associated human activities) have been minor to date (SciencePlus, 2012).

GHG emissions and other externalities associated with energy use depend upon the utilised fuel sources and technologies. Energy from non fossil carbon sources (such as wind and solar power) will generally have significantly lower levels of emissions throughout their life cycle and supply chains though renewable options also have their own unique sets of external costs and benefits.

B. Construction Impacts

Desalination plants are most commonly located near the shoreline (Einav, Harussi and Perry, 2002). As they involve the development of relatively large-scale industrial infrastructure and connecting pipelines, their construction and existence may significantly disrupt coastal environments such as marine and estuarine ecosystems, recreational land uses, landscape and housing amenity and economic values (Einav, Harussi and Perry, 2002; Sadhwani, Veza and Santana, 2005). The usual noise, air quality, access and land use changes during construction (and operation) will apply to desalination as a large infrastructure development and have a range of potentially adverse effects on total economic values.

C. Collection Impacts

The desalination feed-water intake process can have possible adverse impacts upon ecosystems and biodiversity, with risks of impingement and entrainment of organisms (Lattemann and Höpner, 2008). Open water intake is commonly used and, without appropriate management, can result in mortality or injury to aquatic organisms by collision with the intake screens, or by being drawn into the operating plant in the source water. The intake process also has the potential to disturb the surrounding seabed resulting in alterations to the water column. Intake structures can also result in the formation of artificial reefs which may cause interruptions to existing maritime activities, and affect direct economic production and amenity values (Lattemann and Höpner, 2008).

D. Operation - Treatment and Waste Disposal Impacts (Non-Energy)

Desalination processes create a hyper-saline water by-product, called brine, requiring disposal. Brine contains high levels of salts and sometimes contains high concentrations of chemicals and heavy metals (Al-Agha and Mortaja, 2005). The most common method of brine disposal consists of pumping it via a pipeline directly back into the marine environment (Meerganz von Medeazza, 2005; Sadhwani, Veza and Santana, 2005).

The disposal of brine from desalination is typically regarded as the most serious potential source of negative externalities associated with this supply option. If unmitigated, the highly-concentrated salt solution (usually around 70,000 ppm) and possibility of significant chemical and heavy metal residuals can adversely affect the health and functioning of surrounding ecosystems (Al-Agha and Mortaja, 2005; Meerganz von Medeazza, 2005; Sadhwani, Veza and Santana, 2005). SciencePlus (2012, p.14) notes that increased salinity from desalination plant discharges can:

> *"alter the chemistry of the aquatic environment, and this may have detrimental effects on sensitive marine biota. These include short-term impacts on survival and metabolic function due to osmotic effects as the elevated concentration could result in the dehydration of cells. Long-term, chronic effects may arise in the structure of the marine community due to changes in the ability of particular species to compete and avoid predation within the marine ecosystem."*

However, there are strong natural dilution processes at work in most contexts where brine is released and increased salinity is generally considered to be toxic only when concentration levels are very high (ANZECC/ARMCANZ, 2000). Evidence from the Perth Seawater Desalination Plant, operating since 2009, suggests that it has not had significant negative impacts on the water quality and marine ecosystems in the surrounding Cockburn Sound (SciencePlus, 2012).

The chemical composition of brine is the primary source of its potential ecological damage. Before any pre-release treatment, brine can contain:

1. The original chemicals contained in the seawater and brackish feed-water intake (Al-Agha and Mortaja, 2005). These chemicals can include Na, Ca, NO_3, HCO_3, SO_4, Mg, K, and Cl. Brine can contain high concentrations of these chemicals – often well above the concentrations in the receiving waters. For example, the salt concentration of normal seawater is usually around 35,000 mg/L whereas brine will range between 46,000 and 80,000 mg/L.

2. Treatment chemicals added during the desalination process including:
   - Pre-treatment chemicals used to treat the feed-water such as biocides, sulfur dioxide, coagulants (e.g. ferric chloride), anti-scalants (e.g. polyacrylic acid, sulfuric acid, SI-IMP and NaPO), chlorine (used in all plants), polymers, sodium hypochlorite (used for anti-fouling), anti-foaming agents, hydrochloric acid or hydrogen (pH adjustment), sodium bisulfite (chlorine neutraliser), polyelectrolytes and sulfur dioxide (Al-Arha and Mortaja, 2005; Einav, Harussi and Perry, 2002).

- Flushing chemicals used to clean RO membranes and pipelines include: anti-fouling chemicals (e.g. alkylated polyglycols, fatty acids, and fatty acid esters) citric acids, alkaline, polyphosphate, biocides, hydrochloric acid, polyphosphate, sodium compounds, and copper sulphate (Al-Agha and Mortaja, 2005).

3. For thermal desalination processes, in particular, corrosion can produce significant residuals and can lead to the presence of certain other metals in brine (such as copper, nickel, iron, chromium, and zinc.) (Meerganz von Medeazza, 2005).

The environmental externality impacts of brine and can include desertification and reduced marine life reduced soil productivity; and changes to fish migration patterns. Such environmental impacts may have secondary repercussions on commercial fisheries and related production, and a diverse range of direct use, recreation, amenity, existence and bequest values related to potential degradation in water quality and biological productivity. Miri and Chouikhi (2005, p.404) note that the salinity and other physical aspects of discharges can disturb:

- the composition and importance of affected species;
- their abundance in adjacent water;
- their survival rate compared to that existing in natural condition; and
- the species reproductive chain.

Impacts are likely to be more pronounced in shallower estuaries and areas with poor mixing or simultaneously degraded with pollution and other effects of industrial activity.

The discharge of brine can affect the local hydrogeography, water quality, organism/organisational behaviours and ecosystem processes (such as photosynthetic and enzymatic activity) (Miri and Chouikhi, 2005). Brine discharge can also result in alterations to species ratios and diversity – in some cases favouring opportunistic and pest species (Miri and Chouikhi, 2005). A recent study into brine discharge from the proposed BHP Billiton desalination plant at Point Lowly Peninsula, South Australia, found the brine discharge could pose a significant threat to the spawning of the Giant Australian Cuttlefish in the upper Spencer Gulf (Dupavillon and Gillanders, 2009).

Physical and chemical alterations to the receiving environment can result in changes to the physiology and behaviour of marine organisms (Miri and Chouikhi, 2005). Many organisms are either attracted to or repelled by the changes in conditions (Lattemann and Höpner, 2008). This can alter species ratios in the surrounding ecosystems (Lattemann and Höpner, 2008).

The different components that make up brine have specific impacts on marine ecosystems and biodiversity and also adversely affect more general water quality and related economic values. The impacts of salt, metals, treatment chemicals and anti-foaming agents are discussed below. Temperature change impacts are also reviewed though, as noted, these are predominantly associated with thermal process desalination technologies.

High salt levels in brine can lead to ecosystem damage in a number of ways. For example:

(a) The death of organisms located near the outfall system given an inability to tolerate high or marked fluctuations in salinity levels (Al-Agha and Mortaja, 2005; Baalousha, 2006).
(b) High salinity levels can lead to an increase in overall water turbidity in the surrounding area (Miri and Chouikhi, 2005; Dolnicar and Schäfer, 2009). Turbidity reduces the penetration of light and potentially disrupts photosynthesis processes (Miri and Chouikhi, 2005).
(c) A long-term effect can be the formation of a salt desert (marine desertification) in high salinity environments (Miri and Chouikhi, 2005; Dolnicar and Schäfer, 2009).
(d) Increased salt levels may also result in the reduction or extinction of plankton populations (mainly affecting larvae and young individuals). This will, in turn, disturb entire food webs in the locality (Miri and Chouikhi, 2005).

(e) Brine discharge is hypersaline and sinks towards the sea floor as it has a higher density than the receiving waters (Meerganz von Medeazza, 2005; Al-Agha and Mortaja, 2005). This can create a hypersaline sea bed which has the potential to cause significant damage to the local marine biota and ecosystems (Meerganz von Medeazza, 2005; Al-Agha and Mortaja, 2005).

(f) High salinity can increase sedimentation levels. Benthic communities are especially vulnerable and may be buried or stressed by increased deposition (Meerganz von Medeazza, 2005; Al-Agha and Mortaja, 2005).

(g) The deposition of brine onto the seabed can also prevent mixing and dilution and decrease oxygen levels required by marine life (Baalousha, 2006).

(h) Discharged brine can form plumes of highly saline water that stretch over hundreds of metres and may alter the seabed as they spread (Einav, Harussi and Perry, 2002).

(i) If relevant, the discharge of brine may also lead to the contamination of groundwater, via aquifers, increasing the hardness of the groundwater (Al-Agha and Mortaja, 2005; Mohamed, Maraqa and Al Handhaly, 2005).

In addition, when brine is disposed onto land, it can also impact upon the surrounding soil, altering its physical and chemical properties, accumulating surface sodium, and forming a hard outer crust (Al-Agha and Mortaja, 2005; Dolnicar and Schäfer, 2009). It can also alter the electrical conductivity of soil and impair soil permeability thus adversely affecting the productivity of surrounding agricultural land (Mohamed, Maraqa and Al Handhaly, 2005).

For thermal desalination in particular, the brine that is released is usually hotter than the receiving waters. This temperature difference can impair fragile local ecosystems (e.g. corals) (Meerganz von Medeazza, 2005). Higher temperatures can also disturb coastal fish migrations (Baalousha, 2006). Fish sense the salinity or temperature changes and move further offshore, making their total migratory patterns longer, and sometimes deterring them from areas with the highest food density (Al-Agha and Mortaja, 2005). In addition, abrupt temperature changes from desalination plant operations can be lethal to fish (Miri and Chouikhi, 2005).

Calefaction (heating-related) effects apply primarily to thermal desalination. Changes in temperature can have a variety of adverse, or at least disruptive, impacts upon primary production, algae, zooplankton, benthic invertebrates and fish via changes photosynthetic, metabolic, reproduction, breathing and a range of other behavioural, physiological and ecological processes (Miri and Chouikhi, 2005). According to Miri and Chouikhi (2005) and Al-Agha and Mortaja (2005), other potential temperature impacts of brine discharge include:

(a) A reduction in oxygen solubility and depressed oxygen levels which may be life-threatening for certain organisms;

(b) The combined effects of organic loading, elevated temperatures and accelerated rates of bacterial respiration may promote anoxia or hypoxia in marine ecosystems;

(c) Decreases in water density, viscosity, nitrogen solubility, and surface stress where variation in densities can lead to "stratification". Decreased viscosity will foster increased settling rates and sedimentation and reduced nitrogen solubility decreases primary production;

(d) Increased vapour pressure due to the higher temperatures can elevate evaporation levels and change ambient environmental conditions favourable for marine life; and

(e) For land-based discharges, high brine temperatures can kill microorganisms in soil thus reducing soil fertility.

Heavy metals derived from the corrosive processes inherent in desalination are can also exist in the brine discharge (Meerganz von Medeazza, 2005). Their impact will depend upon the specific design of the processes and the environmental conditions surrounding the plant. Heavy metals can lead to fatalities in fish and other aquatic life and tend to disproportionately affect fish eggs, plankton and larvae as they are more likely to become concentrated in the upper seawater layers where these organisms reside (Al-Agha and Mortaja, 2005). When brine is disposed onto land, heavy metals and inorganic compounds can accumulate in the soil and groundwater and, via the food chain, lead to adverse, long-term health issues to human and other species (Mohamed, Maraqa and Al Handhaly, 2005).

In desalination brine, copper (Cu) can be concentrated at levels 200 times higher than ambient seawater and can bio-accumulate in fish tissue throughout the food web (Miri and Chouikhi, 2005; Lattemann and Höpner, 2008). The element copper is very toxic in high concentrations and can lead to fatality in vulnerable organisms. For example, for fish it may cause changes in physiology, and development and reproduction processes. With phytoplankton, it restricts the uptake of nitrate and silicate (Miri and Chouikhi, 2005). Continued exposure to high copper concentrations can elicit pathological responses such as neoplasm formation, genetic derangement and tissue degeneration. Iron (Fe) is another metal found within brine which negatively impacts upon marine environments. Iron, especially when compounded with elevated salt levels, can lead to an increase in water turbidity creating optical pollution and disruption to photosynthesis (Miri and Chouikhi, 2005; Lattemann and Höpner, 2008).

The chemical treatment agents which are added throughout the desalination process can have significant environmental impacts (Meerganz von Medeazza, 2005; Lattemann and Höpner, 2008). In general, the release of these chemicals and metals may contribute to marine desertification, eutrophication, pH value variation, accumulation of heavy metals, and sterilisation of surrounding ecosystems (via disinfectants) (Meerganz von Medeazza, 2005).

Ferric chloride causes discoloration within the receiving waters. Depending on the severity of contaminants, this may interrupt key ecosystem functions such as photosynthesis (Al-Agha and Mortaja, 2005; Lattemann and Höpner, 2008). The chlorine and biocides used are highly hazardous to marine resources (Al-Agha and Mortaja, 2005). The majority of problems associated with the use of biocides are linked to the danger they can cause to non-target organisms such as phytoplankton, meroplankton, ichthyoplankton and holozooplankton (Miri and Chouikhi, 2005). When biocide concentrations reach levels higher than 0.01 mg/L, the consequences for ecosystems becomes more severe. At this level, the phytoplankton photosynthesis slows and zooplankton, post-larval invertebrates and fish may die. Ichthyoplankton tolerance of biocides varies with age – new larvae being more tolerant than older organisms. Chlorine biocide attacks a fish's gills and bronchial epithelium, potentially leading to fatal conditions.

Anti-scaling and anti-foaming substances can have negative effects upon surrounding ecosystems. Anti-scaling agents may cause eutrophication due to increased primary production levels (Miri and Chouikhi, 2005; Lattemann and Höpner, 2008). Anti-scaling agents often consist of polymeric substances such as polycarbonic acids and phosphates. Both of these substances are not highly toxic to aquatic life but exacerbate eutrophication problems (Lattemann and Höpner, 2008). Anti-foaming agents can adversely affect organisms in the surrounding environment by damaging their intracellular membranes (Miri and Chouikhi, 2005). Polyglycols are a common anti-foaming agent and, whilst these chemicals are not toxic, they are persistent in the environment due to poor biodegradability (Lattemann and Höpner, 2008).

Noise pollution can be a serious impact associated with desalination (Tsiourtis, 2001). Operational noise levels from desalination plants can be substantial, posing both nuisance and health and safety hazards to residents, businesses and tourists in the surrounding area (Sadhwani, Veza and Santana, 2005). Careful management and planning may be required to mitigate these impacts.

E. Operation – Energy and GHG Emission Impacts

One of the key arguments frequently raised against desalination is its high energy-intensity of production (energy per kL of water). Estimates of the electricity required to produce 1 m^3 (or 1 kL) of water range between 3 kWh and 20 kWh, with efficiency levels generally being higher for newer plant technologies (Meerganz von Medeazza, 2005, p.59). As around 350 grams of coal is typically required to produce 1 kWh of electricity, the amount of coal combusted will vary between 1.06 and 7.08 kilograms (Einav, Harussi and Perry, 2002, p.152). Therefore, a plant which has an annual output of 100 ML of water would require between 50 – 60 MW of power and approximately 20,000 kg of coal (Einav, Harussi and Perry, 2002, p.152). As with all water supply options, a full life cycle analyses of desalination should take into consideration the substantial emissions of GHG and other pollutants generated from the inputs used in all phases of construction and operation (Sadhwani, Veza and Santana, 2005). The cost of energy is often approximately 25 – 50% of the total cost of the water produced. However, this value varies according to the type of energy used and the energy price levels (Baalousha, 2006; Kalogirou, 2001; Tsiourtis, 2001). Beyond climate change impacts, many other potential issues should be taken into account with regard to desalination if it is tied to fossil carbon energy sources. These issues include energy security, carbon pricing policies, long-term viability in view of global community perspectives, and a host of other externalities associated with this non-renewable energy resource.

RO technology is used in both desalination and wastewater recycling. However, desalination uses 3 - 3.4 kWh/kL, versus water recycling which uses only 0.4 - 1 kWh/kL. Hence, the overall energy costs for desalination can be three to six times higher than for recycling (Dolnicar and Schäfer, 2009, p.890). In Perth, the 45,000 ML per annum desalination plant located at Kwinana became operational in November 2006. The energy intensity of Perth's water supply almost doubled over five years, primarily due to the additional water sourced from this plant (Retamal *et al.,* 2009.

The net economic benefit of desalination is directly tied to the cost of energy as it often constitutes approximately 40% of total production costs. Energy requirements differ across the range of desalination technologies and there can also be substantial variation within technologies, depending on source water quality and design details (Cohen, Wolff and Nelson, 2004).

F. Distribution Impacts

Pipelines are required for the intake of feedwater, return of brine residual water, and to connect the desalinated water to regional or urban water grids. Connecting pipelines tend to have the same potential environmental issues as for most other water supply options though they are often located through relatively low-lying and potentially vulnerable coastal sites. The need to move water from low-lying locations also has increased energy implications. Pipelines are also a potential source of environmental impact during their construction. While this impact tends to be temporary and localised, the effects can be significant in vulnerable environments such as wetlands, rocky habitats and coral reefs. In terrestrial areas, pipelines are potential sources of contamination and pollution to aquifers (Sadhwani, Veza and Santana, 2005; Baalousha, 2006). There is a risk of leakage resulting in the penetration of salty effluent into groundwater (Einav, Harussi and Perry, 2002). This risk increases where drilling is used to draw brackish feed water.

G. Decommissioning Impacts

There is little published information on the decommissioning of desalination plants. This may be due to their relatively new nature and the lack of experience with this life cycle stage. Desalination technology has only become widely used throughout the past few decades. For additional information on the potential impacts of desalination, with a focus upon marine life and the Australian context, also see RPS Environment and Planning (2009) and Danoun (2007).

3.2.3 The Externality Tables for Desalination

The complete listing and short descriptions of major characteristics of the potential externalities identified for desalination are presented in the tables below.

The information is provided in two table formats. Table 8 is intended as a summary table and is a condensed version showing some key features in symbolic form (see the table key and paragraph below) and the reference source codes. Table 9 comprises the extended version with some detail about the nature of the externalities as examined in existing research.

Table 8: Main externalities associated with desalination - Summary table.

Note: positive (+) or negative externality (-); whether impacts tend to occur predominantly downstream (↓), upstream (↑), or within the immediate surrounds of the supply infrastructure (◙).
Reference label numbers are provided at the end of each externality listed. The full reference details are provided in Appendix A.

DESALINATION												
LIFE CYCLE OR OPERATIONAL PHASE	**EXTERNALITY TYPE (showing if positive or negative effect, main location and reference source number)** *(see Appendix A for reference source code details)*											
	Greenhouse Gas Emissions	**Energy**	**Water Quality**	**Nutrients**	**Production**	**Recreation**	**Amenity**	**Health**	**Ecosystem**	**Biodiversity**	**Non-use Values**[1]	**Other** (eg. flood mitigation)
General	- 268, 102	- 223	-, +, ↓, ◙ 126, 101, 102		-,+, ◙ 102	-, ◙ 102	-, ◙ 102	+, ↓, ◙ 102	-, +, ↓, ◙ 102, 223, 126, 41, 101	-, ↓, ◙ 126		+, ↓, ◙ 41
Construction			-, ↓, ◙ 102, 104						-, ↓, ◙ 102, 104, 101, 127			
Collection									-, ↓, ◙ 127			
Treatment	- 104, 105, 269	- 104, 105, 269	-, ↓, ◙ 126				-, ↓, ◙ 126, 102	-, ◙ 104	-, ↓, ◙ 101, 102, 104, 126, 103	-, ↓, ◙ 126, 270		+. ◙ 126
Waste Management			-, ↓, ◙ 126, 101, 102		-, ↓, ◙ 101, 106, 127		-, ↓, ◙ 101		-, ↓, ◙ 126, 101, 102, 127, 126, 103	-, ↓, ◙ 103, 127, 101, 102, 126		
Distribution									-, ◙ 101, 102			
Decommissioning												

1. Non-use values include option, bequest, intrinsic, vicarious and existence values in the total economic value (TEV) scheme.

Table 9: Main externalities associated with desalination – Existing study details.

Note: positive (+) or negative externality (-); whether impacts tend to occur predominantly downstream (↓), upstream (↑), or within the immediate surrounds of the supply infrastructure (◙). Reference label numbers are provided at the end of each externality listed. The full reference details are provided in Appendix A.

<table>
<tr><th colspan="2">DESALINATION</th></tr>
<tr><th>LIFE CYCLE OR OPERATIONAL PHASE</th><th>EXTERNALITY TYPE, DESCRIPTION (showing if positive or negative effect, main location and reference source number)
(see Appendix A for reference source code details) (see inset table to left for externality type codes):</th></tr>
<tr><td>General
<table>
<tr><th></th><th>Externality Type Codes =></th></tr>
<tr><td>GHG</td><td>Greenhouse gas emissions</td></tr>
<tr><td>En</td><td>Energy</td></tr>
<tr><td>WQ</td><td>Water Quality</td></tr>
<tr><td>N</td><td>Nutrients</td></tr>
<tr><td>P</td><td>Production values</td></tr>
<tr><td>R</td><td>Recreation values</td></tr>
<tr><td>A</td><td>Amenity values</td></tr>
<tr><td>H</td><td>Health values</td></tr>
<tr><td>E</td><td>Ecosystem values</td></tr>
<tr><td>B</td><td>Biodiversity values</td></tr>
<tr><td>NU</td><td>Non-use values</td></tr>
<tr><td>O</td><td>Other</td></tr>
</table></td>
<td>GHG: High GHG emissions in comparison to other supply options (-) 268 ,102
En: Most energy intensive of supply options (-) 223
WQ and E: Deterioration of water quality in receiving seawaters (-, ◙) 126
WQ and E: Possible contamination of the underlying groundwater aquifer with the very salty brine (-, ◙) 101, 102
WQ and H: Improvement in water quality and sanitation as it is free of pollutants, carcinogens, organic materials, viruses, and offending tastes and colours. (+,↓, ◙) 102
P: converting the coastal area into an industrial zone, loss of tourism potential (-, ◙) 102
P: source of water free from high concentrations of dissolved salts, sodium, chloride and boron which are harmful to crops. (+ , ◙) 102
R and A: Interruption to coastal recreation sites (-, ◙) 102
E: Leaving surface water supplies in stream and using desalinated water as a partial replacement can generate substantial ecosystem benefits. (+,↓, ◙) 41
E: deteriorations of local hydrography (-, ◙) 126
E: Release of hyper-saline water as a by-product (-,↓, ◙) 223, 102
B: abrupt start-up and shutdown operations at a desalinization plant can be lethal to fish (-, ↓, ◙) 126
O: offers reliability benefits, since it is available even in drought years. (+,↓, ◙) 41</td></tr>
<tr><td>Construction</td><td>WQ and E: Pipes of seawater laid over the aquifer pose a danger to it as these pipes may leak and salt water may penetrate the aquifer and in the case of feed drilling the aquifer may be damaged either by infiltration of saline water or by disturbances of the water table. (-, ↓, ◙) 102, 104
E: Loss of open seashore ecosystems for construction and operations. (-, ◙) 101
E: seawater pipes leak which could contaminate the aquifers and surrounding marine environments (-, ◙) 104, 127
E: Layers of sand and clay may suffer re-suspension during the laying of the pipes and rocky areas and reefs may suffer mechanical blows. (-, ◙) 102</td></tr>
<tr><td>Collection</td><td>E: Extraction of groundwater causes an inland shift, consequently affecting the freshwater–saline water balance (-, ↓, ◙) 127</td></tr>
<tr><td>Treatment</td><td>GHG an En: Highly energy intensive (-)104, 105, 269
WQ, A and E: Fe contained in some additives for the desalination process can lead, when combined with high salinity, to an increase of water turbidity, giving optical pollution and disrupt the photosynthesis. (-, ↓, ◙) 126
A: Noise Pollution: A desalination plant, which is based on reverse osmosis technology, requires high-pressure pumps, which generate lots of noise. (-, ◙) 102
H: High pressure pumps and energy recovery systems, such as turbines or similar, produce significant level of noise over 90 dB(A), this may have health and safety implications for workers (-, ◙) 104
E: All desalination plants use chlorine or other biocides, which are hazardous to marine resources, to clean pipes and other equipment and sometimes to pre-treat the feed water. (-, ↓, ◙) 101, 102
E:Treatment chemicals and flushing chemicals are usually discarded along with brine either directly to the ocean or through the sewage system, the release of these chemicals with brine can cause ‘marine desertification’ (-, ◙) 103, 104, 101, 102
E: Scaling substances can cause eutrophication phenomena (oxygen imbalance) (-, ↓, ◙) 126
E and B: High discharge temperatures result in: decreases in dissolved oxygen which could create life-threatening conditions; anoxia or hypoxia in marine ecosystems (particularly in summer) increased stratification of water bodies; changes to sedimentation; reduction in the solubility of nitrogen which can contribute to a deterioration of primary production and; increases in evaporation (-, ↓, ◙) 126
B: biocides easily kill the organisations not targeted such as the phytoplankton, the meroplankton, the holozooplankton and the ichthyoplankton and fish (-, ◙) 126
B: Brine discharge can disrupt spawning habits of unique species, e.g. the Giant Australian Cuttlefish in the upper Spencer Gulf in SA (-, ◙) 270
B: Anti-foaming agents disturb organism’s intracellular membrane system. (-, ◙) 126
O: Softens the water which assists in preventing clogging of pipes and formation of scale on appliances (+, ◙) 102</td></tr>
</table>

DESALINATION	
LIFE CYCLE OR OPERATIONAL PHASE	**EXTERNALITY TYPE, DESCRIPTION (showing if positive or negative effect, main location and reference source number)** *(see Appendix A for reference source code details)* **(see inset table to left for externality type codes):**
Waste Management	**WQ and E:** Brine discharge can lead to an increase of water turbidity which is likely to disrupt the photosynthesis process, it can create a salt desert in the vicinity of the pipeline outlet and can reduce plankton production to extinction. (-, ◙) 126 **WQ and E:** intake water consists of salts, Cl, Na, K, Ca, Mg, NO3, SO4, HCO3, etc. These chemicals are rejected with brine after treatment also produce liquid wastes that may contain high salt concentrations, salt concentrations above those of receiving waters. (-, ↓, ◙) 101, 102 **P**: Brine discharged into the sewer system causes high pressure on the wastewater treatment process, making it more difficult and requiring special treatment. (-, ↓, ◙) 101 **P**: Brine has both physical and chemical effects on soil. It can damage the soil's physical properties by increasing the concentration of the sodium accumulated on the surface, kills microorganisms, damages the structure and composition of soil, reduces the soil's water-holding capacity and its ability to transmit plant nutrients and it can cause decreasing crop yields due to an overall poor soil quality. (-, ◙) 101, 106 **P, E and B**: may cause severe damage of the marine environment beneath by prevention of mixing and lowering oxygen level and killing organisms residing near the outlet (-, ◙) 127 **A**: Ferric chloride is not toxic but may cause a discoloration of the receiving water if discharged. (-, ↓, ◙) 101 **E**: Concentrations in desalination effluents are 200 fold higher than natural copper concentrations in sea water resulting in bioaccumulation throughout the food web. At elevated levels, Cu is very toxic, it acts as enzyme inhibitor; inhibits photosynthesis, restrict the uptake and assimilation of nitrate and the uptake of silicate; and For estuarine fishes, changes occur in organism physiology, reproduction and development and can produce unfavourable pathological responses. (-, ◙) 126 **E**: Brine contains heavy metals that have an adverse impact on the marine environment. Brine contains chemicals such as anti-scalants that are used in pretreatment of feed water, washing solutions and rejected backwash from the feed water; all of them have an adverse impact on the surrounding environment. (-, ↓, ◙) 101, 102 **E and B**: The high temperature of discharged brine affects migration patterns of fish along the coast and can disrupt fragile ecosystems and communities such as coral (-, ↓, ◙) 103, 127 **E and B:** The high salt concentration of the discharged brine and fluctuations in salinity levels may kill organisms near the outfall. There are disproportionate adverse impacts on benthic communities as brine sinks. (-, ↓, ◙) 101, 102 **E and B**: Brine contains heavy metals that cause death to fish and aquatic life. The heavy metals may become concentrated in the upper part of seawater, which is toxic to fish eggs, plankton, and larvae. (-, ↓, ◙) 101, 102 **B:** Alterations of the biochemical reactions in the receiving water body elicit physiological and behavioural responses in organisms: modifications to the level of the breathing of the communities, the composition of the species, the dynamics of the nutrients and the secondary production ;Depression in rate of phytoplankton photosynthesis; Normal algae populations tend to be replaced by less desirable species: eutrophication; Decrease the production of macro algae populations; Decrease the abundance and diversity of phytoplankton; mortality and reduction in growth and biomass of zooplankton. (-, ◙) 126 **B**: Disposal of brine impacts Benthic invertebrates, causing reductions in biodiversity, reductions in the growth rates of clams, faster growth in oysters and increased mortality in adult populations. (-, ◙) 126 **B:** Under fluctuating temperatures near outfall, fish cannot control their internal thermal balance actively. The fish succumb following certain mechanisms such as: failure of the smooth muscle peristalsis; denaturizing protein in the cells; Increase in the lactic acid in blood; oxygen deficit; inhibition in larval development; erythrocyte's degeneration and lowering of respiratory rate. (-, ◙) 126
Distribution	**E:** seawater pipes leaks which could contaminate the aquifers (-, ◙) 104 **E:** Layers of sand and clay may suffer re-suspension during the laying of the pipes and rocky areas and reefs may suffer mechanical blows. (-, ◙) 102
Decommissioning	

3.3 Dams

There are currently over 45,000 large dams (greater than fifteen metres in height) in use worldwide, with five thousand of these dams constructed prior to 1939 (Stanley and Doyle 2003). The estimated value of these water storages is in the trillions of dollars. The hydrological alteration of a river caused by dams can have a profound and damaging effect on riverine ecosystems causing flow-on social and economic implications (Bergkamp *et al.* 2000, p.iv; Tharme 2003; Graf 2006, p.340).

The World Commission on Dams (WCD) states that current decision making processes do not effectively cost the externalities associated with dams. Decisions are based on providing compensation to impacted communities rather than seeking alternatives, and if social and environmental impacts were given true weighting many dams would not be economically viable (Bergkamp *et al.* 2000). Some studies show that the costs of dam construction, operation and maintenance far outweigh the economic benefits that dams accrue (see Zafarnejad 2009, p.327). In practice, large dams have been less effective than predicted due to climatic change, sedimentation, and the high cost of infrastructure maintenance (Bergkamp *et al.* 2000).

3.3.1 Biophysical Description of Dams

Traditionally, the majority of town water supply in Australia has been from rainfall collected in the catchment areas of dam and reservoir storages. Some regions are now choosing to construct off-stream storages, recognising the impacts dams have on the hydrology and aquatic ecosystems of rivers. Off-stream storage is the extraction of water from a river via a pump and pipeline to storage in large tanks or off-stream reservoirs. Figure 7 shows the water cycle demonstrating the process of rainfall capture, storage in dams and the subsequent treatment and distribution to urban centres.

3.3.2 Impacts

A. General Impacts

An externality that must be considered when a dam is being considered as a new water supply is the damage caused by damming a river to the eco-systems and biodiversity of the catchment (Kingsford 2000, p.109; Bell *et al.* 1980; Harris 1984; Walker 1985; Chessman *et al.* 1987; Doeg *et al.* 1987; Marchant 1989; Walker and Thoms 1993 all in Kingsford 2000, p.111). Dams impact on the variability, magnitude, frequency, duration, timing and rate of change of a rivers natural flow regime (Graf 1985; Zafarnejad 2009; Magilligan and Nislow 2005, p.61). This natural flow regime is essential for sustaining ecosystem integrity (Poff *et al.* 1997). Any alterations to the regime can result in significant sediment, nutrient, chemical and temperature changes, all which can have serious ecological and economic consequences (Bergkamp *et al.* 2000, p.iv).

The impact of a dam on any river is unique and dependent on the local climatic conditions, hydrology, geology and biota, as well as many other site specific variables. Table 10 lists some of those hydrological changes and their implications to the surrounding environment. Dams have been found to contribute to the decline of many threatened and endangered species (Graf 1985) as well as causing deforestation (Zafarnejad 2009). The range of potential human health impacts is summarised in Table 11.

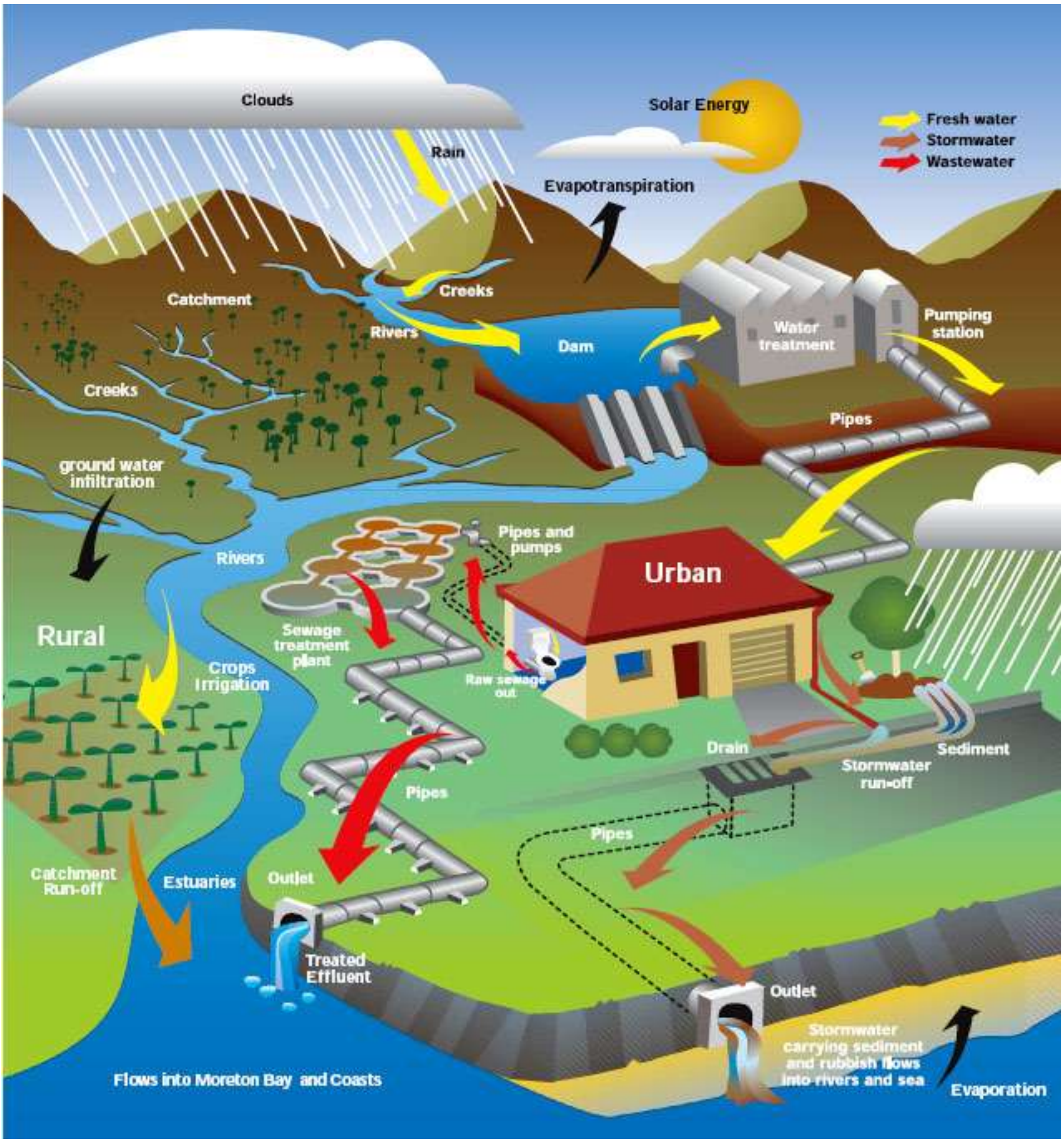


Figure 7: The urban water cycle for the Brisbane area.

Source: Healthy Waterways (2009).

Table 10: Potential hydrological changes as a result of dams and dam operations.

Potential hydrologic changes as a result of dams and dam operations, along with the geomorphic and ecologic effects

Hydrologic parameters	Geomorphic implications	Ecologic implications
Instantaneous maximum flow	Amount of available space for river forms, sediment, and processes; flood plain size	Amount and types of patches for aquatic and riparian organisms
1-day maximum flow	Overall channel morphology, number and size of functional surfaces	Hydration in riparian habitats for terrestrial animals
30-day maximum flow	Dominant particle size of bed materials, flood-plain changes	Long-term dehydration in riparian habitats for terrestrial animals, duration of stressful high temperatures, low oxygen
Date of maximum flow	Interactions between erosive flows and stabilizing vegetation	Habitat cues for reproduction and survival behaviors in aquatic and riparian organisms.
Maximum/mean flow	Spatial range of processes, frequency and sizes of functional surfaces	Size, variety, and distribution of habitat patches for aquatic and riparian organisms
Mean daily flow	Size of ordinarily active low flow channel, channel pattern, geomorphic complexity	Amount of habitat space, patch size, amount of water available for organisms, amount of food and cover, access by predators to nesting sites, soil moisture availability for riparian plants, food and cover, availability of habitats
Instantaneous minimum flow	Limit on sediment transportation, channel maintenance	Limits for aquatic organisms
1-day minimum flow	Sediment storage and mobility	Balance among competitive stress-tolerant organisms
30-day minimum flow	Particle sizes distributions of bed material	Stability of channel habitats for fishes
Date of minimum flow	Interaction between vegetation and deposition processes	Habitat cues for reproduction and survival behaviors in aquatic and riparian organisms
Date of minimum flow	Interaction between flows and riparian vegetation that invades active channel areas	Access to nesting habitats, isolation from predators during nesting, habitat cues for survival and reproduction
Range of daily flows	Spatial extent of active area of functional surfaces	Habitat patch size
Number of reversals	Overall annual stability of channels and banks	Frequency of changes in marginal aquatic and riparian habitats
Mean up-ramp rate	Likelihood of erosion of banks, bars, islands	Entrapment of terrestrial organisms on islands and flood plains, inundation stress on plants and low-mobility stream-side organism
Mean down-ramp rate	Likelihood of erosion of banks, bars, islands	Entrapment of aquatic organisms in abandoned pools and channels, drought stress on plants and low mobility stream-edge organisms
Number of high flow pulses	Frequency of mobility of channel bed and bank materials, frequency of changes in functional surfaces	Access for water birds to feeding and nesting sites
Mean duration of high flow pulses	Magnitude of erosion on banks and in channels, bedload transport, channel sediment texture,	Utility of aquatic habitats for organisms, especially for reproduction
Number of low flow pulses	Length of time for stability of channels and banks, frequency of depositional regimes in channels	Frequency and magnitude of soil moisture change or anaerobic stress for plants, availability of flood-plain habitats for aquatic organisms
Mean duration of low flow pulses	Magnitude of deposition processes in channel	Nutrient and organic matter exchanges between river and flood plain, soil mineral availability

Source: Graf (2006, p.346).

Whilst causing significant ecological damage, there are a number of social and economic benefits attributed to dam construction including:

- Food security and protection from droughts in chronically vulnerable areas (Schultz 2002, p.151);
- generation of hydropower energy (Schultz 2002, p.150);
- productive efficiency of irrigation. (Schultz 2002, p.151);
- improved navigation;
- some flood protection; and
- expanded recreation opportunities (Graf 1999, p.1305).

Table 11: Potential human health impacts of large dam projects.

Impact Area	Effect of Dam	Health Impact
Upstream catchment and river	Loss of biodiversity, increased agriculture, sedimentation and flooding, changes in river flow regime	Changes in flood security, water-related diseases, difficulties with transportation and access to health facilities
Reservoir area	Inundation of land, presence of large man-made reservoir, pollution, changes in mineral content, decaying organic material, pollution	Involuntary resettlement, social disruption, vector- borne diseases, water-related diseases, reservoir- induced seismicity
Downstream river	Lower water levels, poor water quality, lack of seasonal variation, loss of biodiversity	Food security affected on flood plains and estuaries (farming and fishing), water-related diseases, dam failure and flooding
Irrigation areas	Increased water availability and agriculture, water weeds, changes in flow and mineral content, pollution	Changes in food security, vector-borne and water- related diseases
Construction activities	Migration, informal settlement, sex work, road traffic increase, hazardous construction	Water-related diseases, sexually transmitted diseases, HIV/AIDS, accidents and occupational injuries
Resettlement areas	Social disruption, pollution, pressure on natural resources	Communicable diseases, violence and injury, water- related disease, loss of food security
Country/regional/global	Reduced fuel imports, improved exports, loss of biodiversity, reallocation of funding, sustainability	Macro-economic impacts on health, inequitable allocation of revenue, health impacts of climate change

Source: Lerer and Scudder (1999, p.115).

It is argued that the above developments also incur the social costs marginalisation of communities and increased health risks (see Table 14). The industrialisation of agriculture made possible through the construction of large dams for irrigation, whilst increasing food production, has exacerbated the inequality between the wealthy and traditional subsistence farmers as well and lead to widespread land clearing and mono-cropping (Schultz 2002, p.150; McCully 2001).

B. Construction and Inundation Impacts

The construction of a dam results in the submergence of large areas of land upstream (Marsden Jacob Associates 2007b). The externalities associated with inundation are discussed below.

(i) Social

One of the most devastating social impacts of a dam is the displacement of residents who live within the catchment area. The disruption and loss of livelihood for the affected communities is one of the most harmful consequences of large reservoir construction (Baxter 1977, p.275). High levels of stress caused by involuntary resettlement and community disruption have also been recorded (Lerer and Scudder 1999).

The submerged land is typically of high agricultural value and the loss of access to this resource impacts on the economy and food availability in the region (Schultz 2002). The submergence of forested regions results in the loss of access to timber and also a number of native species that may also have medicinal properties (Tilt, Braun and He 2009, p.251). Large dams also lead to cultural loss through the submergence of culturally significant sites (McCully 2001; Zafarnejad 2009, p.338; Baviskar and Singh 1994, p.356).

Relocation to either urban centers or nearby communities can result in the loss of indigenous knowledge and culture (Zafarnejad 2009, p.337). Through the resettlement process, family members and communities are likely to be separated. This has consequences for emotional wellbeing, as well as breaking support systems and the pooling of resources. Facilities and resources provided for resettlement to displaced persons has often proven inadequate (Baviskar and Singh 1994).

The migration and resettlement of people near dam sites changes the rural economy and employment structure; which in turn impacts on infrastructure and housing; impacts on non-material or cultural aspects of life; and impacts on community health and gender relations (Tilt, Braun and He 2009, p.S249). Dam construction also causes increased traffic to the region and may facilitate increased industrial activity, which can have flow on environmental impacts (Queensland Water Infrastructure 2008).

There are a number of other potential risks for local communities from the construction of dams. These risks include death, injury, and illness resulting from poor working conditions and dam breakages (Bergkamp *et al.* 2000). The migration of male workers to a region may create an opportunistic sex trade and a subsequent increase in sexually transmitted diseases (Lerer and Scudder 1999, p.114).

(ii) Ecosystems

The flooding that occurs upstream of a dam submerges vast areas of land having a dramatic impact on the local eco-system. A number of wetlands have been submerged by the construction of dams in Australia including, Lake St Clair Great Lake, Lake Pedder (Tasmania) and Lagoon of Islands (Tyler 1976; Kirkpatrick and Tyler 1988 both in Kingsford 2000, p. 111). Submerged vegetation decomposes leading to a depletion of oxygen in deeper levels of the reservoir and may lead to eutrophic conditions and blue-green algae infestations (Zafarnejad 2009, p.336; Bergkamp *et al.* 2000). This bottom layer can become anoxic and reduced substances such as sulfide, ferrous, and manganous ions may accumulate (Baxter 1977, p.261). Decaying submerged vegetation has also been found to release high levels of green-house gases (Murray *et al.* 2010).

The submergence of dry ground also may cause leaching from the soil of toxic substances that are naturally occurring or deposited through previous land-use activities. Changes to the erosion and deposition processes may cause the release of accumulated pollutants from the sediments (Baxter 1977, p.262). The riparian region of a river or lake provides food and habitat for many species. This environment is inundated during the construction of a dam and then periodically afterwards as dam levels fluctuate (Baxter 1977, p.269; Kingsford 2000, p.109). Terrestrial grasses may grow in this riparian zone, however, in many regions, little growth occurs in this zone and the region resembles a barren mud flat rather than providing the riparian vegetation required for many aquatic species (Baxter 1977, p.269; Graf 1985).

The reservoir created for a dam on a river is different to that of a natural lake (Baxter 1977, p.258). The difference can be seen in the longitudinal profile, whereas natural lakes are usually deepest in the centre, river reservoirs are usually deepest just upstream from the dam. This affects surface currents which will not dissipate in shallow waters as they would in natural lakes, thereby causing increased erosion of the shoreline (Baxter 1977, p.258). This in turn may lead to large scale landslides due to the increased shore erosion, as well as increased seismic activity that can be induced by the filling of reservoirs (Baxter 1977, p.259).

(iii) Biodiversity

Dam construction can also impact on the biodiversity of the region. When a dam is constructed, the conditions previously favorable to lotic benthos are replaced with lentic organisms, resulting in populations of plankton growing (Baxter 1977, p.264). The submergence of an area of land will also impact on the fauna native to that region. Many habitats are submerged, particularly those indigenous to river valleys. This significantly reduces the number of diverse habitats for different species and may permanently decrease a species population (Baxter 1977, p.271; Zafarnejad 2009, p.327).

During the filling of a new reservoir, many animals are trapped and drowned and this can be particularly devastating if it occurs during nesting season. The construction of access roads can also destroy habitats (Bergkamp *et al.* 2000). A recent study found that dams and diversions "contributed to the decline of more threatened and endangered species than any other resource-related activity" (Losos *et al.* 1995; Graf, 2006, p.337).

C. Collection / Catchment Management Impacts

The main externalities caused by the collection of water in a dam are associated with the retention of sediments. The high rate of sedimentation in reservoirs impacts on the productivity of the reservoir and greatly reduces the amount of sediment in the water released downstream, having profound effects on ecosystems as well as reducing the productivity of downstream floodplains (Bergkamp *et al.* 2000; Manouchehri and Mahmoodian 2002). The water released down stream is known as sediment or nutrient 'hungry' and picks up new sediment also contributing to considerable erosion of the river channel (Bergkamp *et al.* 2000).

Reservoirs have high levels of sediments deposited within them from upstream and shoreline processes. Stream sediment loads are created by sheet erosion of the surrounding land. This is exacerbated when the land is cleared for agriculture. The other process causing sedimentation of streams is gully erosion of the stream itself or the tributaries and drainage channels. The sediment is then carried by the stream to the reservoir where it settles. However, if the stream has a shallow gradient the sediment may be deposited upstream (Baxter 1977, p.259). The deposition of sediment within the reservoir leads to a reduction in reservoir capacity (Bergkamp *et al.* 2000, p.iv; Baxter 1977, p.259).

High nutrient levels in reservoirs cause eutrophic conditions that lead to blue-green algae outbreaks. Blue-green algae is toxic and the prevention and treatment of algal blooms in reservoirs is one of the high operation costs involved in the use of reservoirs for domestic and agricultural water supplies (Falconer 2006).

Sedimentation also has a negative impact on biodiversity. The most obvious forms of degradation occur when critical components of habitat, such as spawning gravels and cobble surfaces are physically covered by fines. These ultimately decrease inter-gravel oxygen and reduce or eliminate the quality and quantity of habitat for fish, macroinvertebrates, and algae (Lisle 1989; Waters, 1995). Increased deposition of fine sediments has been repeatedly shown to decrease macroinvertebrate diversity and abundance and to reduce the survival of benthic-spawning fishes (Richards and Bacon 1994; Waters 1995; Angradi 1999; Hicks *et al.* 1991; Wu 2000).

D. Storage Impacts

The externalities associated with large storages are varied. Whilst facilitating a number of beneficial recreational activities, a number of health and environmental impacts must be recognised.

(i) Health

Large dam storages can attract a number of water-related diseases such as schistosomiasis, whose lifecycles suits stagnant bodies of fresh water. The occurrence of this disease at the Sardar Sarovar Dam, India, and the adjacent villages was nearly double that of other villages in the region served by the local health centre (Baviskar and Singh 1994, p.353; Baxter 1977, p.275). Other diseases that have been documented to occur after the construction of dams or large irrigation projects include: encephalitis, hemorrhagic fevers, gastroenteritis, intestinal parasites, and filariasis including onchocerciasis and bancroftosis (Lerer and Scudder 1999, p.114; Baviskar and Singh 1994, p.354).

(ii) Ecosystem

The construction of a large dam may also alter the local climate. Changes that may occur are alterations to the precipitation pattern, an increase in low stratus clouds, and interference in the relationship between temperatures and the seasons resulting in knock-on effects to local agricultural seasons (Baxter 1977, p.275). As well as altering the climate the water impounded in the reservoir may impact on local groundwater regimes. Water from reservoirs may seep into the surrounding soil, raising the water table (Baviskar and Singh 1994, p.352).

(iii) Recreation

Large reservoirs provide social benefits, with regards to being a site for a variety of recreational activities (Graf 1999; Bergkamp *et al.* 2000). Fishing is a popular activity on reservoirs as there are large stocks of fish for both sport and commercial opportunities. High fish stocks occur in rivers due to high food sources and the habitat provided by the submerged vegetation for young fish. However, reservoir conditions can also pose a threat to fish breeding. Receding water levels can expose fish eggs and the anoxic conditions created by the high nutrient levels can result in fish kills if certain weather conditions mix the anoxic water with the surface water. Certain parasites also proliferate in reservoirs and may reduce fish stocks. Despite these dangers, fish stocks are generally high in reservoirs (Baxter 1977, p.270).

E. Extraction and River Regulation Impacts

The most significant externality associated with dams is the impact on the natural flow regime of the river, particularly in facilitating the removal of large volumes of water and flood regulation, causing the deterioration of health of the river. The loss of resources reliant on periodic flooding downstream and the loss of riverine fisheries are among the impacts. Externalities associated with river water extraction from dams for water supply to towns and farms as well as those associated with the regulation of river flow for flood control and hydropower are discussed below.

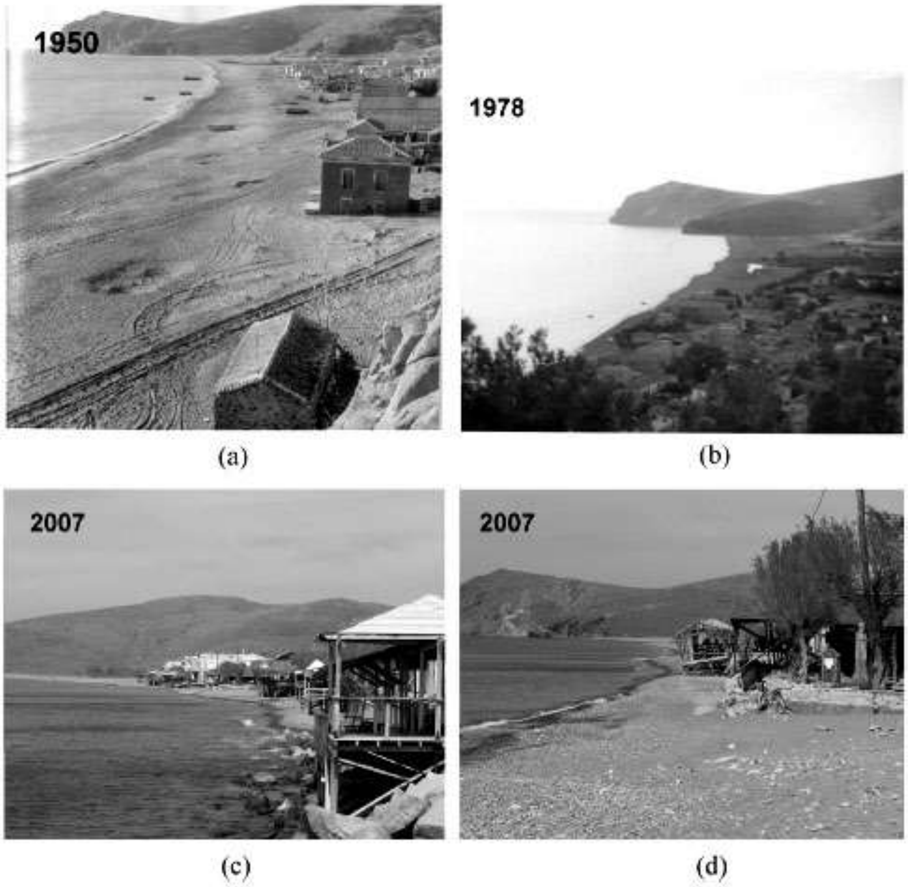
(i) Ecosystems

It is commonly agreed by ecologists that a catchment needs every drop of rain that falls within it and the construction of infrastructure to supply large quantities of water for off-stream use will harm the environmental values of the catchment (Gardner and Chung 2010, p.2; Graf 1999). Due to the reduction in the magnitude, frequency and duration of flood flow, the aquatic plants, animals and microbes that have adapted to unpredictable flood events often cannot survive (Graf 2006 p.340; Petts and Lewin 1979 in Erskine 1985; Milliman 1997 in Kingsford 2000, p. 109). The reduced flows affect the ecosystem by causing a significant change of the river food web (Molles *et al.* 1998; Nislow *et al.* 2002; Wootton *et al.* 1996 all in Magilligan and Nislow 2005, p.62). Species such as the eucalypts that are found on floodplains may survive for up to 20 years without a flood; however other seeds and eggs of aquatic species have less flexibility (Boulton and Lloyd 1992; Brock, Smith and Jarman 1999).

Reducing water availability and submergence are some of the mechanisms through which dams have eradicated forests and accelerated desertification (Zafarnejad 2009, p.327). The downstream flow is further reduced by the high rates of evaporation, seepage and extraction from the reservoir (Graf 1999 p.1308). Downstream water may become saline due to the absence of periodic flushing and dilution by flood water (Bergkamp *et al.* 2000). Comparisons of regulated and unregulated rivers have demonstrated that dams can have damaging impacts on downstream ecosystems (Graf 1985). Regulated rivers produce less diverse riparian ecosystems compared to unregulated rivers (Graf 2006 p.336; Doyle *et al.* 2005 in Graf 2006). The temperature and water level changes caused by dams disrupt the natural aquatic life cycles and promote the dominance of invasive, exotic species (Magilligan and Nislow 2005).

As well as riparian vegetation, the changes in flow regime also impact on downstream floodplains, wetlands, estuaries and beaches. The timing and duration of floods is also important to the species that have adapted to suit the specific conditions (Boulton and Lloyd 1992; Walker *et al.* 1995 in Kingsford 2000). Australia has a high variability in flood frequency and rare large floods help maintain population abundance across landscapes for decades (Kingsford *et al.* 1999). The effect of changes to the timing of floods on food webs and other ecological processes requires further investigation (Power *et al.* 1996 in Magilligan and Nislow 2005; Kingsford 2000, p.111).

Estuaries have complex relationships between the fresh water flowing out to sea over the nutrient-rich seawater flowing upstream that leads to a high level of productivity in the upper layer. The change in flow pattern impacts the species that proliferate in these conditions (Baxter 1977, p.274). The impacts of damming a river can be found at the beaches located at the lower reaches, where sediment previously destined for the beaches is instead retained by the dam (Kingsford 2000, p.111; Velegrakis *et al.* 2008, p.350; EEA 2006; Poulos and Collins 2002b). Figure 8 below shows the severe beach erosion that can occur as a result of dam construction on a river that drains into nearby coastal regions.



(a) Eressos Beach in 1950, (b) Eressos Beach and the village of Skala Eressos in 1978, (c) and (d) Eressos Beach at Skala Eressos in summer 2007 showing severe beach erosion and destruction of the seawall and the promenade.

Figure 8: Beach erosion at Eressos Beach, Greece 1950 – 2007.
Source: Velegrakis et al. (2008, p.353).

(ii) Biodiversity

Aquatic species are also greatly impacted by dam construction. Floodplains provide an important habitat for fish species during the early stages of their life cycle and reducing flood events leads to declining fish populations (Geddes and Puckridge 1989; Gehrke *et al.* 1995, 1999; Harris and Gehrke 1997 all in Kingsford 2000). Fish populations reduce due to the impediment of the dam to fish migration and breeding activities (Bergkamp *et al.* 2000, p.iv). For example some species of the Pacific salmon, blockage of streams for a time, such as for example, during the construction of a dam, could effectively eliminate the population of these species from the stream (Baxter 1977, p.273; Schultz 2002, p.154). Floodplain wetlands are also an important site for bird species that use them for breeding. Colonial water birds (e.g. ibis, egrets and herons) breed on only a few large floodplain wetlands in Australia (Marchant and Higgins 1990; Kingsford and Johnson 1999 both in Kingsford 2000; Magilligan and Nislow 2005, p.62).

The release of water from dams often differs in temperature and chemical composition to that of the natural river flow. The biological effect downstream from the temperature variation can be damaging for aquatic species. Due to processes of stratification, water released from greater depths in a dam is cooler and will consequently affect the population of warm water fish species. There are a number of externalities of dams that are used for hydro-power generation. One of these is known as gas-bubble disease and occurs when fish ingest water supersaturated with gasses causing injury or death (water becomes supersaturated with gas when water mixes with air in the turbine or if water falls from a great height) (Baxter 1977, p.272).

(iii) Social / Productivity

Many communities are affected by lost livelihoods from dam construction. This is because of the diminished productivity for those involved in the fishing and agriculture industries downstream from a dam (McCully 2001; Adams 1985 in Manyari and de Carvalho 2007, p.6527). Flood mitigation functions provided by the dam may cause the degradation of agricultural and grazing resources on downstream floodplains (Bergkamp *et al.* 2000, p.v). Large dams also influence the health of husbandry animals through increases in diseases such as river fluke in cattle and changes in the distribution of trypanosomiasis (Stanley and Alpers 1975 in Lerer and Scudder 1999, p.114). Downstream, the communities who rely on the estuary for amenity can lose their fisheries, tourist attractions, and recreational facilities (Zafarnejad 2009, p.337).

F. Decommissioning Impacts

Dam removal is increasingly being assessed for its potential as a river restoration mechanism. By returning riverine conditions and sediment transport to formerly impounded areas, riffle/pool sequences, gravel, and cobble have reappeared, along with increases in biotic diversity. Improved opportunities for fish mitigation have been another benefit of dam removal. Short-term ecological impacts of dam removal may result in an increased sediment load which can cause suffocation and abrasion to various biota and habitats. However, several recorded dam removals have suggested that this will only exhibit a short-term effect. Although monitoring and dam removal studies are limited, a continued examination of the possible ecological impacts is important for quantifying the resistance and resilience of aquatic ecosystems (Bednarek 2001).

3.3.3 The Externality Tables for Dams

The complete listing and short descriptions of major characteristics of the externalities identified for dams are presented in the tables below.

The information is provided in two table formats. Table 12 is intended as a summary table and is a condensed version showing some key features in symbolic form (see the table key and paragraph below) and the reference source codes. Table 13 comprises the extended version with some detail about the nature of the externalities as examined in existing research.

Table 12: Main externalities associated with dams - Summary table.

Note: positive (+) or negative externality (-); whether impacts tend to occur predominantly downstream (↓), upstream (↑), or within the immediate surrounds of the supply infrastructure (◙).
Reference label numbers are provided at the end of each externality listed. The full reference details are provided in Appendix A.

DAMS												
LIFE CYCLE OR OPERATIONAL PHASE	**EXTERNALITY TYPE (showing if positive or negative effect, main location and reference source number)** *(see Appendix A for reference source code details)*											
	Greenhouse Gas Emissions	**Energy**	**Water Quality**	**Nutrients**	**Production**	**Recreation**	**Amenity**	**Health**	**Ecosystem**	**Biodiversity**	**Non-use Values**[1]	**Other** (eg. flood mitigation)
General				-,↓, ◙ 115	+, -,↓, ◙ 109, 110, 115, 121	+, -, ◙ 115, 125		+,↓, ◙ 110, 115	-, ↑, ↓, ◙ 111, 124, 125	-,↓, ◙ 111, 118	-, ◙ 124, 125	+,↓, ◙ 110, 115
Construction and Inundation					-, ◙ 223,121			-,↓, ◙ 109, 117	-, ◙ 223	-, ↑, ↓, ◙ 109, 125	-, ◙ 108, 120, 125	
Catchment Management/ Collection			-,↓ 119		-,↓, ◙ 119, 125		-,↓, ◙ 125	-, ◙ 125	-, +, ↑, ↓, ◙ 109, 111, 118, 119, 114, 125	-,↓, ◙ 111, 118, 125		
Storage			-,↓, ◙ 92	-,+, ◙ 125	-,+, ◙ 125, 109	-,+, ◙ 125, 109	-,+, ◙ 125	-,+, ◙ 109, 125, 117, 108	-,+, ↓, ◙ 125, 109	-,+, ↓, ◙ 125, 109		
Water Extraction			-,↓ 125		+, -, ↑, ↓, ◙ 125, 109, 121, 117, 45		-, ◙ 109 125	-, ◙ 125	-, ↑, ↓, ◙ 125, 109, 111, 115	-, ↑, ↓, ◙ 109, 45, 125, 116		
Decommissioning												

1. Non-use values include option, bequest, intrinsic, vicarious and existence values in the total economic value (TEV) scheme.

Table 13: Main externalities associated with dams – Existing study details.

Note: positive (+) or negative externality (-); whether impacts tend to occur predominantly downstream (↓), upstream (↑), or within the immediate surrounds of the supply infrastructure (◙).
Reference label numbers are provided at the end of each externality listed. The full reference details are provided in Appendix A.

<table>
<tr><th colspan="2">DAMS</th></tr>
<tr><th>LIFE CYCLE OR OPERATIONAL PHASE</th><th>EXTERNALITY TYPE, DESCRIPTION (showing if positive or negative effect, main location and reference source number)
(see Appendix A for reference source code details) (see inset table to left for externality type codes):</th></tr>
<tr><td>General
<table>
<tr><th></th><th>Externality Type Codes =></th></tr>
<tr><td>GHG</td><td>Greenhouse gas emissions</td></tr>
<tr><td>En</td><td>Energy</td></tr>
<tr><td>WQ</td><td>Water Quality</td></tr>
<tr><td>N</td><td>Nutrients</td></tr>
<tr><td>P</td><td>Production values</td></tr>
<tr><td>R</td><td>Recreation values</td></tr>
<tr><td>A</td><td>Amenity values</td></tr>
<tr><td>H</td><td>Health values</td></tr>
<tr><td>E</td><td>Ecosystem values</td></tr>
<tr><td>B</td><td>Biodiversity values</td></tr>
<tr><td>NU</td><td>Non-use values</td></tr>
<tr><td>O</td><td>Other</td></tr>
</table></td>
<td>N: changes sediment throughput (-,↓, ◙) 115
P: Climatic changes in surrounding areas, e.g., fog, decrease in air temperature etc., which may affect the growing season (-, ◙) 109
P: Contributes to improved efficiency of irrigation and protection from droughts (+,◙) 121
P, H, O: Decreases in flood frequency (+,↓, ◙) 110, 115
R: Dams can provide recreational opportunities in themselves such as, boating, fishing but may interfere with recreational opportunities provided by free flowing rivers, photography and rafting etc (+,-, ◙) 115, 125
E: The shrunken, simplified geomorphology produces less diverse riparian ecosystems (-,↓, ◙) 111
E: altered basic hydrologic regimes (-, ↑, ↓, ◙) 111, 124 E : Degradation of coastal deltas (-,◙) 125
E: Potential cause of deforestation 124 B: contribute to the decline of threatened and endangered species (-) 111
B: Decreases in the quality and quantity of habitat for fish, macro-invertebrates, invertebrates and algae (-, ↓, ◙) 118
NU: Free flowing rivers are often a source of spiritual and aesthetic values and provide inspiration and 'uplifting personal experiences'. Dams will mean these values are lost (-, ◙) 125
NU: Disruption to indigenous cultures (-,◙) 124</td></tr>
<tr><td>Construction and Inundation</td>
<td>P, E: Inundation of large tracts of land (-, ◙) 223 P: Farms lost due to inundation and water logging (-, ◙) 121
H: Stress related to involuntary resettlement and community disruption (-, ◙) 117
H: The inundation of previously dry ground may lead to the release of toxic substances and to the release of pollutants accumulated in sediments (-, ↓, ◙) 109
B: Many mammals and bird nests and habitats are destroyed during inundation which can potentially lead to permanent decreases in population (-, ↑, ↓, ◙) 109
B: Access roads and blasting during construction can cause significant disruption to animals, especially during sensitive phases of the life-cycle (-, ◙) 125
NU: Displacement of people living in designated region - loss of heritage/culture, sense of place, community and kinship features, community disruption etc (-, ◙) 108
NU: Potential loss of heritage sites through inundation, also loss of access to medicinal plants and foods and loss of access to natural sites which are submerged (-, ◙) 120, 125</td></tr>
<tr><td>Collection/Catchment Management</td>
<td>WQ and E: Salinisation of river water (-,↓) 119
P: Diminished fishing and agricultural productivity downstream (-,↓) 119
P, A, E and B: Changes in sediment loads cause massive disruptions to ecosystems downstream and can reduce productivity of floodplains (-, ↓, ◙) 125
E: riparian ecosystems, dependent on floods, are likely to experience large-scale changes (-, ↑, ↓, ◙) 111 E: Hardening of the river bed (-, ↑, ↓, ◙) 119
E: Alterations to sediment regimes means that there is often a build up of sediment within the reservoir which reduces capacity (-, ↓, ◙) 125
E: erosion of banks and streambeds accompanied by a widening or narrowing of channels and coarsening of streambed material (-, ↓, ◙) 125
E: Temperature and water level changes may have severe ecological consequences (+ and -, ↑, ↓, ◙) 109
E: Disruption to haline circulation resulting in biological consequences in fragile estuary ecosystems (-,↓, ◙) 109
E: Contribute to downstream beach erosion (-,↓, ◙) 114, 125 E: Significant reduction in downstream flows and runoff (-,↓,) 115
E and B: Temperature and water level changes may disrupt aquatic life cycles and contribute to adjustments in riparian community structure ultimately promoting dominance of invasive exotics (-, ↓, ◙) 118
B: altered maximum and minimum flows influence certain avian species' migration, nesting and foraging behaviours (-,↓) 111
B: Flooding, caused by dams, may extirpate native riparian forest communities, subsequently reducing biodiversity and causes major changes in river food webs (-, ↓, ◙) 118</td></tr>
</table>

DAMS	
LIFE CYCLE OR OPERATIONAL PHASE	**EXTERNALITY TYPE, DESCRIPTION (showing if positive or negative effect, main location and reference source number)** *(see Appendix A for reference source code details)* **(see inset table to left for externality type codes):**
Water Extraction	**WQ, P and E:** Salinisation of water below dams as a result of evaporation and in wetlands and floodplains as a result of the absence of periodic flushing and dilution by flood water (-,↓) 125 **P**: In the tropics grasses may grow down to drawdown zone providing increased productive grazing area (+, ◙) 109 **P:** As reservoir levels recede, the submerged land—rich with fertile soil and silt deposits—can produce valuable crops (+,◙) AND can cause increases in domesticated livestock diseases and alter downstream food production capabilities which may jeopardise food security of the region (-,◙) 121, 117 **P and B**: disruption of fish migration and spawning of anadromous and catadromous fish and smolts (-,↓, ↑, ◙) 45, 109 **A**: Drawdown zone in temperate climates achieves little growth, hence areas often turn into ‘unattractive mud flats’ (-, ◙) 109 **A and B:** Variation of water levels out of sync with natural regimes has a negative impact on plants in the immediate vicinity of reservoir, can create barren landscapes (-, ◙) 125 **H and E:** Increased risk of the bioaccumulation and contamination of food webs with mercury and other heavy metals (-, ◙) 125 **E**: Littoral ecosystems often subject to particularly severe conditions mainly concerning frequent fluctuations in water levels (-, ↑, ↓, ◙) 109 **E**: large dams are likely to constrain ecosystems that flourish on active flood plains due to reduced inundation and this altered hydrology can also reduce groundwater recharge in the riparian zone, lowering the groundwater table and degrading riparian vegetation (-, ↓, ◙) 111, 125 **E:** channels downstream from dams degrade through erosion related to the trapping of sediment in the reservoir behind the dam (-,↓) AND disrupted downstream hydrologic and biotic systems (-,↓) 115 **B:** Temperatures downstream can be altered by reservoir discharge and this can affect spawning, growth rates and the length of the growing season (-,↓) 125 **B:** reduced flows downstream can lead to habitat reduction which may increase likelihood of extirpation or extinction of vulnerable populations (-, ↓, ◙) 125 **B:** Interruption to bivalve and gastropod mollusc lifecycles and significant decreases to fish biodiversity (-, ◙) 125 **B**: Gas-bubble disease in fish can cause injury or death, arises due to impacts of turbines of water plunging over spillway into deep basins (-, ◙) 109 **B**: reduced water reaching floodplain/ altered flows: Aquatic plants, sedentary animals and microbes adapted to unpredictable flood events eventually die, reduced floodplain habitat for young fish leads to declining populations, water-birds which breed only on large floodplain wetlands decline (-) 116
Decommissioning	

3.4 Wastewater Recycling (Centralised)

Wastewater recycling for indirect potable reuse has proven to be one of the most controversial water supply options available in Australia. While the reuse of wastewater holds great potential, there are many barriers to its adoption. The most significant barriers are the community acceptability issues of wastewater commonly being perceived as 'toilet to tap' water as well as the lack of confidence in wastewater management (Shäfer and Beder 2006, p.242). In 2005, 97% of urban runoff and 86% of total wastewater in Australia was estimated to be returned directly into waterways, meaning only 9 – 14% of wastewater was actually recycled (Dimitriadis 2005, p.17). Table 14 describes the use of wastewater reuse as a percentage of the total wastewater available.

Table 14: Estimates of water reuse by State and Territory from water utility sewerage treatment plants in Australia 2001-2002 in gigalitres (GL).

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	1,824	166.5	9.1

Source: Dimitriadis (2005, p.19).

Table 14 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, p.2). Wastewater discharge is high in nutrients that damage aquatic ecosystems and cause algal blooms (Toze 2004, p.2). Considering the high population growth predicted for SEQ, this amount of wastewater produced is set to rise exponentially and the stress on waterways will also increase. 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 the reduced discharge provides.

Wastewater recycling can occur on a number of scales and is commonly divided into either centralised or decentralised systems. This section of the report on the identification of externalities associated with the use of recycled water refers to centralised wastewater recycling systems. Centralised systems generally comprise large networks of sewer pipes to transport the wastewater across the city to a central treatment plant and dispose of treated effluent in rivers or oceans (Cook *et al.* 2009).

Decentralised systems are usually designed for smaller spatial scales such as individual homes, clusters of homes, urban communities, industries, or built facilities, as well as from portions of existing communities either independent from or as part of a larger system (Cook *et al.* 2009). As noted in the *Queensland Guidelines to Decentralised Wastewater Systems 2007*, scale differences between centralised and decentralised systems are also accompanied by different management responsibilities. The operation and maintenance of centralised systems is the responsibility of municipal authorities whereas decentralised systems are operated independently (Cook *et al.* 2009).

Centralised systems are the focus of this report as they comprise the majority of wastewater systems in urban SEQ and have significant impacts upon rivers and waterways. However, increasingly, decentralised systems are being viewed by developers, local government authorities and residents as being a viable water supply option for headwork charges, set-up costs and irrigation costs and therefore may be included as an option in the next stage of this project.

3.4.1 Biophysical Description of Wastewater Recycling

Water recycling differs from the hydrologic cycle by requiring consideration of technical, health, environmental and social externalities when developing, operating and regulating the wastewater treatment plants as part of the recycling process. Figure 9 illustrates the integration of human recycled water systems within the hydrologic cycle.

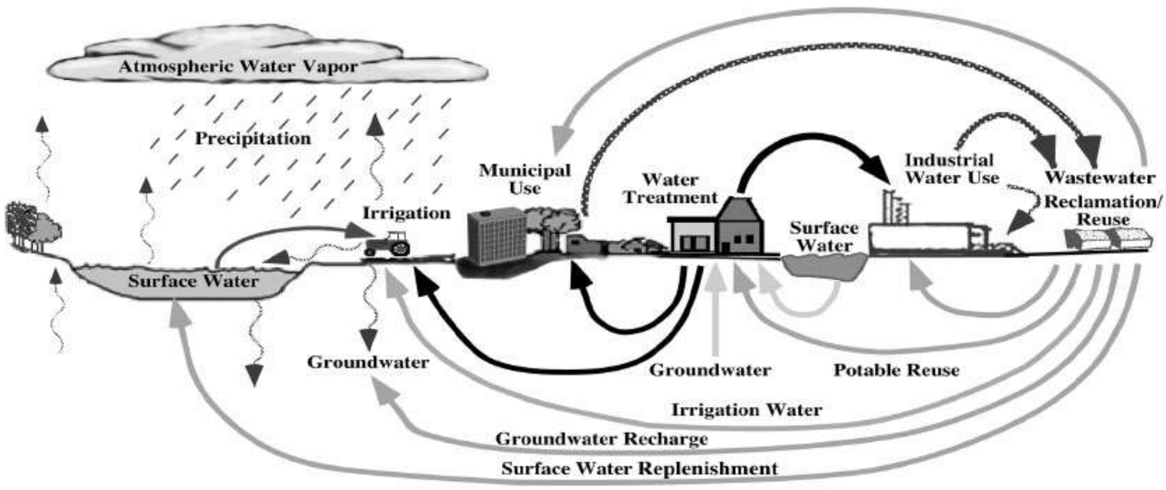


Figure 9: The role of engineered treatment, reclamation, and reuse facilities in the cycling of water through the hydrologic cycle.

Source: Asano (2001, p.5).

The first stage of the wastewater recycling process involves the harvesting of wastewater from sewage reticulation. Sources of wastewater include; homes, shops, offices and factories, farms, transport and fuel depots, vessels, quarries and mines (DERM 2010). The collected wastewater is then transferred to a wastewater treatment plant via gravity flow or a series of wastewater pumps stations and pressurised pipes. Wastewater treatment, the second stage of the process, can be divided into primary, secondary and tertiary treatment (DERM 2010) (see Table 15 for details).

Table 15: Treatment stages at a sewage treatment plant.

Primary treatment	Removes solid matter. Larger solids, such as plastics and other objects wrongly discharged to sewers, are removed when wastewater is passed through screens. Smaller particles, such as sand, are removed in grit traps. Wastewater then flows into large tanks where solids settle and are removed as sludge. Grease and scum are skimmed from the surface.
Secondary treatment	Uses tiny living organisms known as micro-organisms to break down and remove remaining dissolved wastes and fine particles. Micro-organisms and wastes are incorporated in the sludge. There are two main types of secondary treatment: aerobic and anaerobic.
Tertiary treatment (or disinfection)	Removes disease causing micro-organisms. Suitable and cost-effective disinfection methods for cities include adding chemicals to effluent and irradiation with ultraviolet light. In less populated areas, effluent may be held in lagoons or ponds for several weeks, allowing micro-organisms to die off before the effluent is released.

Source: DERM (2010, web page).

Biological nutrient removal (BNR) is increasingly being used for the removal of nitrogen and phosphorus, however it is not available at all sewage treatment plants because it requires expensive and specialised equipment (DERM 2010).

To produce water quality that is of a standard equal to or more pure than potable water, some wastewater treatment plants use ‘advanced water treatment’. Two common types of advanced water treatment technologies are microfiltration and reverse osmosis. Microfiltration involves passing wastewater through very fine hollow fibre membranes (WaterSecure 2009, p.2). These membranes remove particulate matter, protozoa and some viruses. After passing through the membrane, the filtered water contains only dissolved salt and organic molecules. Reverse osmosis is another method of advanced water treatment and the same process used to desalinate seawater. This involves forcing water through specialised membranes at high pressure to remove dissolved salts, viruses, pesticides, and most organic compounds. Advanced water treatment also provides an opportunity to reduce nutrient loads through reverse osmosis concentrate nutrient removal.

Figure 10 describes the recycled water treatment process employed by the Western Corridor Water Recycling Scheme; it uses a number of primary, secondary, tertiary and advanced water treatment techniques (see Table 15).

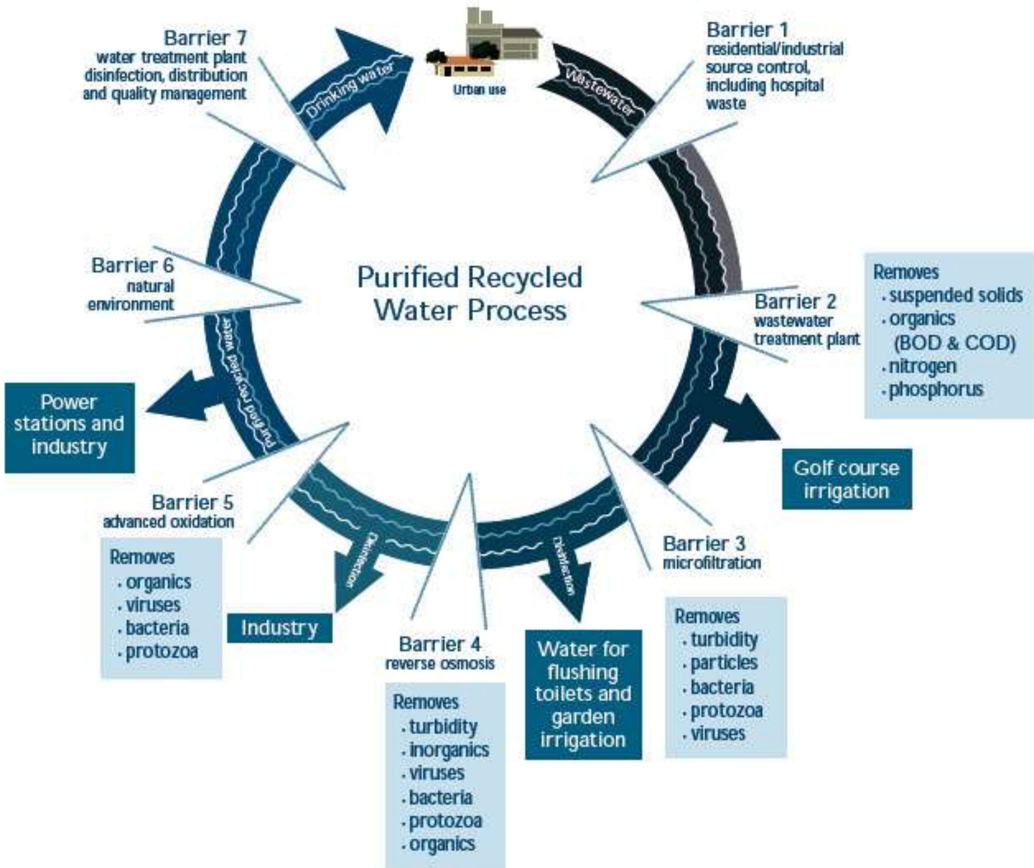


Figure 10: The seven-barrier water treatment process used in the Western Corridor Purified Recycling Water Scheme.

Source: Queensland Water Commission (2008, web page).

Following treatment, recycled water is distributed for specific uses that are dependent on the quality of the water, the control measures in place and the availability of infrastructure for the transportation of water (Dimitriatis 2005, p.22). In Queensland, the quality of recycled water is the responsibility of the water service provider, and is defined by the government quality standards (DERM 2008, p.16). Recycled water is commonly used for the following purposes:

- Landscape irrigation of golf courses, parks, sports fields;
- Industrial uses such as cooling, laundries, car washing facilities;
- Agricultural uses such as irrigation of produce, pastures for animal feed, and plant nurseries;
- Emergency use in dust suppression and fire-fighting;
- Use in office buildings for toilet flushing;
- Aquaculture (the cultivation of aquatic organisms like fish); and
- Groundwater recharge (Dimitriadis 2005, p.17).

Recycled water that is distributed to residential, commercial, and industrial buildings for certain non-potable uses is known as 'third pipe' or 'dual reticulation'. Dual reticulation is the simultaneous supply of water from two separate sources, requiring two sets of pipes. One pipe provides water for drinking, cooking and bathing purposes; the second provides recycled water for other non-drinking purposes. Figure 11 below shows the combination of drinking water and recycled water supply that comprises dual reticulation. Effluent reuse schemes and community rainwater tanks are examples of dual reticulation systems that can be established to offset the use of drinking water within designated reticulated water supply areas. Dual reticulation systems are approved on a case-by-case basis by councils using a risk management approach (Department of Local Government and Planning 2009, p. 10).

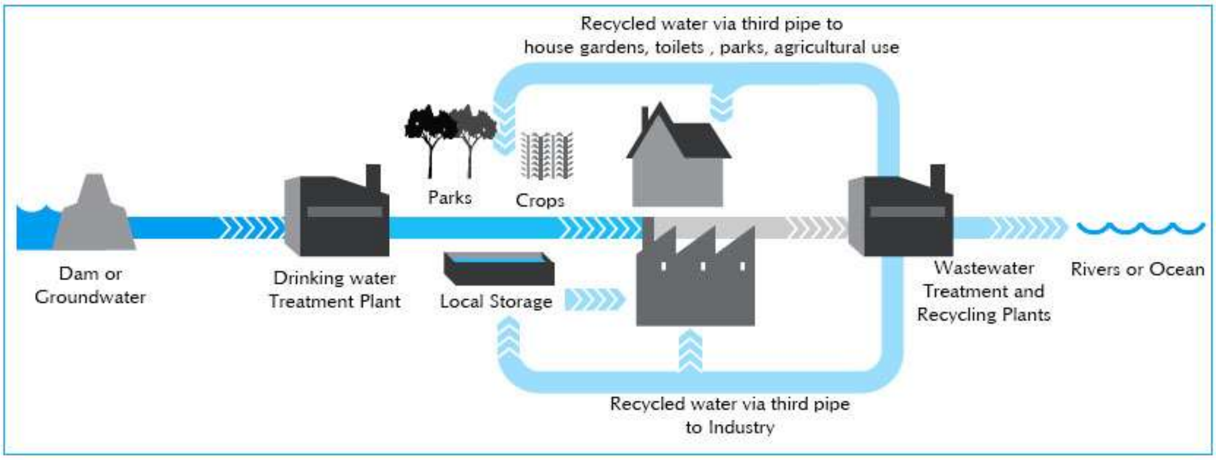


Figure 11: Schematic of wastewater dual reticulation, also known as 'third pipe' systems.
Source: WSAA (2006, p.8).

Water that is treated to a standard equal to or higher than potable water is known as Purified Recycled Water (PRW) and can potentially be used for indirect potable reuse. Indirect potable reuse is recycled water that is of a quality suitable for drinking which is then mixed into the water supply storage, such as a dam or aquifer, before being distributed into the drinking water system (National Water Commission 2008).

Biosolids are the stabilised organic solids that are the by-product of treated wastewater (Australian Water Association 2010). Biosolids are usually transported to a landfill or reused as a fertiliser. Biosolids contain organic matter and plant nutrients and hence provide a useful soil conditioner. There are formal guidelines for biosolids reuse to minimise public health risks and environmental damage. As with recycled water, there is a high degree of public acceptance towards the use of biosolids projects, provided procedures for managing the risks are in place. The major risk regarding biosolids is human contact causing infection from microorganisms (National Resource Management Ministerial Council 2004, p.4).

3.4.2 Impacts

A. General Impacts

There are a series of key positive externalities of wastewater reuse. Firstly, it can reduce damage to aquatic ecosystems, as wastewater is reused rather than discharged to rivers and oceans (Asano 2001, p.2). 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, p.17; Davis 2006; Brennan *et al.* 2003 p.5; WSAA 2006, p.4). 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). Wastewater reuse is predicted to be more effective in reducing potable usage than demand management (Stenekes *et al.* 2006, p.115).

There are many negative externalities associated with the impact of wastewater discharge on the ecosystem 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 ecosystems. 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 (Dimitriadis 2005, p.18).

B. Collection Impacts

The collection of wastewater is commonly achieved via a sewerage reticulation system 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, p.27). 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 (DERM 2006). Trade waste requires careful management to ensure that contaminated waters do not enter the stormwater system (Environmental Protection and Heritage Council 2007).

C. Treatment Impacts

Wastewater treatment facilities produce and release methane and CO_2 as well as having high energy consumption (Cakir and Stenstrom 2005, p4203). As a result, environmentalists often promote water conservation as a less intrusive alternative (Davis 2006, p3). In both urban and agricultural settings, wastewater recycling is far less energy intensive than any physical source of water other than local surface water (Cohen, Wolff and Nelson 2004, p.vi). A research brief prepared by Dr. Sophia Dimitriadis, for the Department of Parliamentary Services, on recycling schemes estimated the energy consumption per kilolitre of potable water produced for various water supply options. The standard requirements for energy consumption in Australia are:

- 3 to 5 kilowatt hours (kWh) for reverse osmosis of seawater;
- 0.4 to 0.6 kWh for conventional water treatment;
- 0.7 to 1.2 kWh for brackish reverse osmosis; and
- 0.8 to 1.0 kWh for wastewater reclamation (Dimitriadis 2005, p.27).

Whilst energy consumption for water recycling was higher than conventional water treatment, it was substantially lower than for desalination.

The major uses of electricity at a wastewater treatment plant are: the bioreactors (aerated using air compressors); UV disinfection globes; mechanical handling of sludge; and the pumping of wastewater. Anaerobic digestion has lower energy consumption as well as a lower biomass production than aerobic digestion. However, it has a much slower digestion process and requires a greater storage area to achieve the same water quality. Biological nitrogen and phosphorus removal also have high energy consumption. The main by-product of nitrogen removal is nitrogen that is released into the atmosphere; for phosphorus removal it's the production of carbon dioxide.

The production of greenhouse gases from treatment plants also provides the opportunity for the capture and reuse of the emissions for electricity generation. The Oxley wastewater treatment plant in SEQ produces electricity through the production and capture of methane from its primary anaerobic digesters. Methane is a by-product of the biological digestion of organic compounds in anaerobic conditions. The plant produces enough electricity to power approximately two thirds of its power requirement. Figure 12 below identifies the sources of greenhouse gases within the recycled water system for the Sydney region.

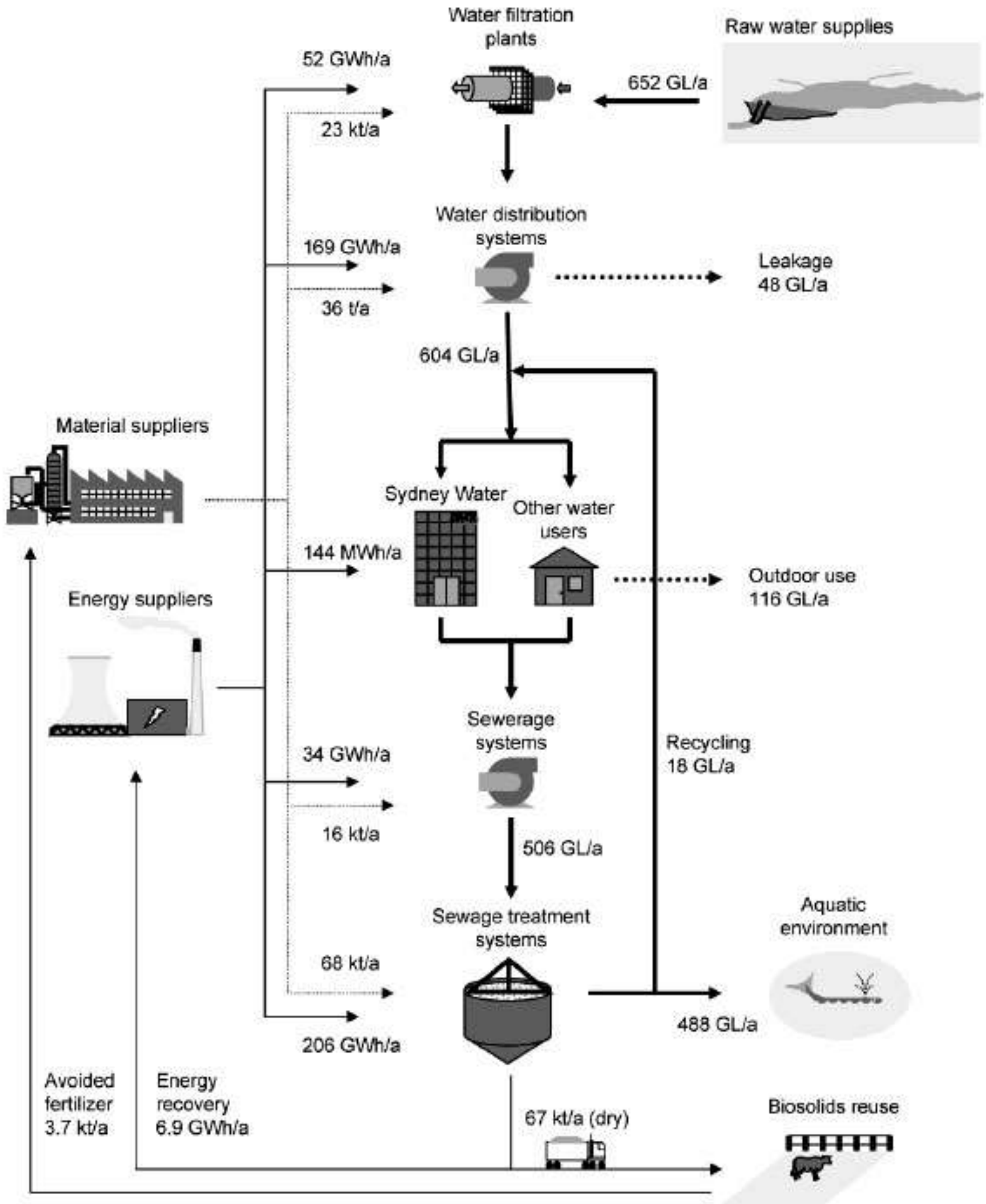


Figure 12: Simplified flow diagram within the defined system boundaries for the Sydney water system.
Source: Lundie, Peter and Beavis (2004,p.3468).

D. Use/Distribution Impacts

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; primary production; irrigating parks, gardens and other open spaces; aquifer recharge; and to supplement surface water supplies (Dimitriadis 2005, p.18). Wastewater is a reliable and constant supply option which is independent of rainfall and has provided support for numerous drought-constrained regions (WSAA 2006, p.6; Angelakis, Bontoux and Lazarova 2003, p.59). An example of this is a dairy farm in Shoalhaven, NSW, that used urban wastewater to survive a drought period (Dimitriadis 2005, p.18).

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, p.18; Toze 2004, p.5; Angelakis 2003, p.65). 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 of fertiliser but can also have adverse effects through excessive microbial activity which may cause detrimental impacts on soil porosity (Toze 2004, p5). 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). 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 green spaces 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. The inclusion of these benefits into cost benefit analysis may imply that the community may be better served by the development of recycled water than by the purchase of other supplies that are considered less expensive (but are rainfall dependent) (Davis 2006, p.2).

Recycled water also offers potential benefits for restoring wetlands and other natural habitat by eliminating or reducing overdraft of groundwater supplies (Davis 2006, p.3). 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, p1941).

Transportation of water is a primary consideration for recycling schemes since the locations where water is to be reused may not yet be serviced by pipes (Dimitriatis 2005, p.22). Existing pipes often cannot be used because recycled water needs to be kept separate from standard drinking water. Moving water from these locations can therefore require significant capital works expenditure and subsequent pumping costs (or alternatively trucking costs) to meet immediate service needs. Plumbing an existing subdivision with new pipes to deliver recycled water is unlikely to be economically efficient (Dimitriadis 2005, p.22). In addition, there are significant costs associated with installing the infrastructure to enable delivery to agricultural areas (WSAA 2006, p.13).

Wastewater can also be mixed back into dams and groundwater aquifers to supplement drinking water supplies subject to its quality, appropriate management and control (WSAA 2006, p.3; Toze 2004, p.1; Angelakis, Bontoux and Lazarova 2003, p.61). This is the most controversial use of recycled water due to potential health impacts. Recycled water can be a source of enteric pathogen contamination eg, viruses, bacteria, protozoa, nematodes and helminthes (Toze 2006; Asano 2001; O'Toole, Leder and Sinclair 2007). Other water quality factors of concern include: total mineral content (eg, total dissolved salts); heavy metals; pharmaceuticals such as antibiotics and pain killers (eg, paracetamol); radionuclides (eg, chemotherapy by-products); and concentrations of stable organic substances, pesticides, hormone-affecting and cancer-causing compounds excreted into the sewerage system (Dimitriadis 2005, p.25). These chemicals pose a health risk, particularly if water is to be considered for drinking (O'Toole, Leder and Sinclair 2007, p.999).

The risk of human exposure to recycled water is through: 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, p.422). Due to these risks it is important to address water quality issues and usage through stringent guidelines (Asano 2001, p.1941).

In addition to the biological risks, particular concern has also been raised regarding the pharmaceutically active residuals and endocrine disrupting chemicals (EDCs) that may be found in wastewater (Toze 2004, p4). These compounds have been found to be only partially be 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, p.215). 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, p.422).

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, p.4). 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, p.15). However, nanofiltration may not be a complete barrier to micropollutants such as hormones (Nghiem *et al.* 2004, p.219). Due to the continually expanding 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, p.6).

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). This has caused significant quantities of recycled water to be ingested by citizens (Brown 2009, p.5). Recently, the Melbourne Water office connected low grade recycled water to the drinking water tap in one of its administration buildings, leading to illness affecting 12 staff (Brown 2009, p.5).

Whilst it is commonly accepted that there are a number of benefits associated with the use of recycled water, there are also a number of barriers surrounding issues of social acceptability. These are primarily related to health concerns. A survey by the Urban Water Security Research Alliance 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 are: lack of public confidence; health; environment 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). Table 16 highlights the varying levels of acceptance depending on the designated use of the recycled water.

Table 16: Recycled water acceptance.

Use of Reclaimed Water	Strongly Favour	Favour	Don't Know	Oppose	Strongly Oppose
Golf courses parks gardens	60.5	36.1	0.4	2.7	0.3
Flushing toilets public buildings	56.5	37.7	1.4	3.6	0.9
School yards and playing fields	45.0	41.6	1.7	10.8	0.9
Commercial laundries	34.9	40.2	3.2	19.4	2.3
Dairy, beef and sheep pasture	32.4	43.6	3.7	18.6	1.7
Vineyards	29.6	44.3	3.5	19.7	2.9
Vegetable and fruit crops	28.9	39.3	3.4	24.6	3.8

Source: Marks, Martin and Zadoroznyj (2008, p.92).

These results are consistent with the embedded cultural understandings of the appropriate management of effluent. This is reflected in the two most highly accepted uses, both of which are unlikely to involve personal contact (Marks, Martin and Zadoroznyj 2008, p.92). Notions of cultural significance are seemingly supported by the rejection of indirect potable reuse in the city of Toowoomba, Queensland (Marks, Martin and Zadoroznyj 2008, p.97). Wastewater use also has the potential to offend cultural or religious sensitivities (Morgan 2006).

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 are less able to do so (Nancarrow *et al.* 2007, p.28; Miller and Buys 2008). Another way equity issues arise is through wastewater treatment plants being disproportionately located in low-income neighbourhoods (Davis 2006, p.3).

E. Waste Management Impacts

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 into stormwater drains (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 of this is Struvite, produced at the Oxley WWTP in Queensland from nutrients found in the biosolids for use as a commercial fertiliser. This helps to lower the nutrient content of biosolids currently going to landfill which have the potential to contaminate groundwater as leachate. Phosphorus is a non-renewable resource currently being sourced from phosphate rocks; hence, the recycling of phosphorus from sewage back into a source for plant growth may be increasingly important in the future, should traditional stocks become depleted.

The management of biosolids is highly energy intensive. It involves transportation to landfill or to reuse as a fertiliser product and the process produces approximately the same amount of GHG as the wastewater treatment process (Lundie, Peter and Beavis 2004, p.3468).

F. Decommissioning Impacts

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

3.4.3 The Externality Tables for Wastewater Recycling

The complete listing and short descriptions of major characteristics, of the externalities identified for wastewater recycling are presented in the tables below.

The information is provided in two table formats. Table 17 is intended as a summary table and is a condensed version showing some key features in symbolic form (see the table key and paragraph below) and the reference source codes. Table 18 comprises the extended version with some detail about the nature of the externalities as examined in existing research.

Table 17: Main externalities associated with wastewater recycling - Summary table.

Note: positive (+) or negative externality (-); whether impacts tend to occur predominantly downstream (↓), upstream (↑), or within the immediate surrounds of the supply infrastructure (◙). Reference label numbers are provided at the end of each externality listed. The full reference details are provided in Appendix A.

WASTEWATER RECYCLING (Centralised)												
LIFE CYCLE OR OPERATIONAL PHASE	**EXTERNALITY TYPE (showing if positive or negative effect, main location and reference source number)** *(see Appendix A for reference source code details)*											
	Greenhouse Gas Emissions	**Energy**	**Water Quality**	**Nutrients**	**Production**	**Recreation**	**Amenity**	**Health**	**Ecosystem**	**Biodiversity**	**Non-use Values**[1]	**Other** (eg. flood mitigation)
General		**(+)** 41	**(+, ↑,↓,◙)** 141, 134, 135		**(+,-, ◙)** 130, 134	**(-,◙)** 141		**(-,↓,◙)** 130, 137, 131, 133 , 267, 242, 130, 149	**(+, -, ↑, ↓, ◙)** 141, 134, 135, 133	**(+,-, ↓, ◙)** 141, 135, 130	**(-,◙)** 129, 139, 283	**(-,+,↓, ◙)** 141, 267, 41, 129, 139, 142, 160, 155
Collection								**(-,◙)** 277	**(-, +, ↓, ◙)** 134, 155, 145			**(-, +,↑,↓,◙)** 155, 133, 135
Treatment			**(-,↓, ◙)** 141,129, 138		**(+,-,◙)** 135, 133			**(-,+,↓,◙)** 129, 138, 130	**(-,◙)** 133			**(-,◙)** 133
Distribution/ Use (Non-Potable)	**(-)** 129				**(+,◙)** 129, 155, 133, 130, 135	**(+,◙)** 130, 155, 135	**(+,-,↓,◙)** 156,130, 145,138	**(-,↓, ◙)** 145, 160	**(+,-,↓,◙)** 141, 155, 133, 134, 145	**(+,↓, ◙)** 129	**(-)** 183	**(+, -, ↑, ↓, ◙)** 155, 133, 145, 135,141
Waste Management					**(+,-,◙)** 133	**(+,↓, ◙)** 129			**(-, +, ↓, ◙)** 129, 155, 145			**(-,↓, ◙)** 155
Decommissioning												

1. Non-use values include option, bequest, intrinsic, vicarious and existence values in the total economic value (TEV) scheme.

Table 18: Main externalities associated with wastewater recycling – Existing study details.

Note: positive (+) or negative externality (-); whether impacts tend to occur predominantly downstream (↓), upstream (↑), or within the immediate surrounds of the supply infrastructure (◙). Reference label numbers are provided at the end of each externality listed. The full reference details are provided in Appendix A.

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 A for reference source code details)* (see inset table to left for externality type codes eg. En = energy)
General	**En:** Water recycling is a highly energy efficient water source (+) 41 **WQ and E:** Eliminating or reducing overdraft of groundwater supplies (+, ↑, ↓, ◙) 141, 134 **WQ, E and B:** Avoiding degradation of receiving waters (e.g., pollution of streams or freshwater intrusion into saltwater habitats) (+,↓, ◙) 141, 135 **P:** Support for drought constrained farming (+,◙) 130, 134 **P:** Risk of soil contamination due to build up of water residues (Salinity, boron etc) (-,◙) 130 **R and O:** Enables people to maintain activities requiring water, e.g. garden maintenance, whilst not promoting water waste (-,◙) 141 **H:** Risk of contamination and consequent health issues (-,◙) 130, 137 **H:** Risk of cross-connections leading to contamination (-,◙) 131 **H:** Potential source for enteric pathogen contamination (e.g. viruses, bacteria, protozoa, nematodes, and helminths) (-,↓, ◙) 133 , 242 , 267 , 137 **H:** Recycled water contains higher levels of EDCs (Endocrine Disrupting Chemicals) than most other water sources. 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. (-,↓, ◙) 133 **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. (-,◙) 130 **H and O:** sewage farm workers and their families may experience more serious health risks, this creates equity issues. (-, ◙) 267 **H:** risk of accidental construction faults leading to leakages, contamination or leaching AND risk of purposeful sabotage or damage (-, ◙) 149 **E:** Reduces the discharge of harmful effluents into receiving environments where they can cause eutrophication and algal blooms. (+,↓, ◙) 133, 135 **E:** prevention of coastal pollution (+, ↑, ↓, ◙) 135 **E:** reduce pressure on the highly stressed deep groundwater levels and recover pressured aquifer systems (-,↓, ◙) 134 **B:** Protecting aquatic species by avoiding additional diversions from streams, and rivers (-,↓, ◙) 141 **NU:** community perceptions of risk and disempowerment (-,◙) 129, 139, 283 **O:** offers reliability benefits, since it is available even in drought years. (+,↓, ◙) 41, 129 **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. (-,◙) 139, 142, 160 **O:** Diversifies water sources and therefore strengthens water security. (+,↑,↓, ◙) 155
Collection	**H:** Potential contamination from industrial and agricultural discharges (-,↓, ◙) 277 **E:** When stored on site, risk of leakage under storages, leading to pollution of groundwater and possible lateral flow to the adjoining streams (-,↓, ◙) 134 **E:** Reduces discharges and runoff to the environment by capturing water and nutrients that may otherwise be discharged from wastewater treatment plants into stormwater drains (+,↓) 155, 145 **E:** risk of excessive recharge and transport of solutes to the groundwater system (-,◙) 134 **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). (-,◙) 155 **O:** Constant and reliable supply (+) 133, 135 **O:** Independent of rainfall which is increasingly unreliable - water security implications (+, ↑, ↓, ◙)155
Treatment and Disinfection	**WQ:** The nature of wastewater, which has higher concentrations of nitrite, ammonia, and organic nitrogen than most drinking water supplies, increases the likelihood of certain water quality problems. (-,↓, ◙) 141 **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. (-,↓, ◙) 129, 138 **P:** using recycled wastewater for irrigation can reduce the need for fertiliser thanks to the nutrients it contains. This may even remove the requirement for tertiary wastewater treatment (+) 135 **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 (-,◙) 133 **H:** In some cases there may be a Improvement of water quality due to more comprehensive and rigorous monitoring systems (+,↓, ◙) 129 **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**) (-,↓, ◙) 130 **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. (-,◙) 133

	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

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 A for reference source code details)* (see inset table to left for externality type codes eg. En = energy)
Distribution/ Use (Non-Potable)	**GHG**: Transportation of water is a primary consideration for recycling schemes since the locations where water is to be reused may not yet be serviced by pipes (-) 129 **P**: Recycled water can provide a supply of nutrients useful when irrigating crops and providing a source for fertiliser (+,◙) 129, 133 **P:** Recycled water can significantly increase agricultural productivity through utilising nutrients such as nitrogen and phosphorus. This also reduces the cost of energy-intensive upgrades of treatment plants to enable nutrient removal (+,◙) 155 **P and R:** Increased tourism and recreation as result of maintenance of recreational spaces (golf courses and gardens etc) (+,◙) 130, 135 **R and A:** Capacity to use water for public amenity and recreational spaces (e.g. irrigation of parks, sporting grounds and gardens) (+,◙) 155 **A:** Increased ability to maintain green spaces, gardens etc (+,◙) 130, 138 **A, E and O:** In order to get the recycled water from the treatment plant to an area where it can be used, would involve building long and expensive pipelines and pumping which would consume significant amounts of energy. In addition re-plumbing of existing homes may be required and this involves significant disruption and dislocation within societies (-, ↑, ↓, ◙) 155, 145 **H:** Risk of cross-contamination (-, ◙) 145 **H:** The results indicate that nano-filtration may not be a complete barrier to many micro-pollutants such as hormones which may result in very high temporary permeate concentrations. (-, ◙) 159 **E:** Allows maintenance of environmental flows, restoring wetlands and other natural habitats (+,↓, ◙) 141, 134 **E:** Reduces the discharge from wastewater treatment plants into rivers and oceans (+,◙) 155 **E:** Capacity to make improvements to environmental flows to urban waterways (+,↓, ◙) 155 **E:** The persistence of PhACs (pharmaceutically-active compounds) may lead to the development of antibiotic resistance in soil microorganisms. (-, ◙) 133 **B**: Provision of new supplies for environmental enhancement and aquifer recharge (+,↓, ◙) 129 **O:** Avoid the need for investment into upgrading wastewater treatment plants (+, ↑, ↓, ◙) 155 **O:** Constant and reliable supply (+, ◙) 133, 135 **O:** Wastewater treatment (including treatment expansions needed to support water recycling) is disproportionately located in low-income neighborhoods, raising environmental justice issues. (-) 141 **NU:** May offend cultural or religious sensitivities (-) 183
Waste Management	**P:** additional nutrients can be a bonus as a source of additional fertiliser but can also have adverse effects through excessive microbial activity and growth and detrimental impacts on soil porosity. (-, +, ◙) 133 **R**: Less release of effluent to coastal waters means lessening of concerns associated with contamination of bathing waters and aquatic ecosystems (+,↓, ◙) 129 **E**: reducing the quantity and improving the quality of effluent discharged to coastal waters (+,↓, ◙) 129 **E:** Treatment produces 'concentrate'/by-product which would be discharged via ocean outfalls when sufficient storage is unavailable. (-,↓, ◙) 155 **E:** potential for nutrient and contaminant runoff, nutrient and contaminant build-up in soils and possible contamination of groundwater if this recycled water is applied inappropriately. (-,↓, ◙) 145 **E and O:** High levels of transport and therefore cost associated with managing the 'concentrate'/by-product from the recycled water processes. This concentrate (when derived from RO technology) contains all impurities removed from the wastewater. Thus whilst the volume of liquid discarded decreases the load of impurities does not (-,↓, ◙) 155
Decommissioning	

3.5 Groundwater

Groundwater is an important source of fresh water, representing over 90% of the world's readily available fresh water. The demand for water is increasing due to population growth and better technology making it easier to access water. However, as the demand for groundwater increases, deeper wells must be dug and since aquifers recharge slowly, wells will eventually dry up unless extractions are kept within sustainable limits. The United Nations Environment Program (UNEP) and the World Health Organisation (WHO) identify some of the reasons for overuse of groundwater as; unclear water rights, unregulated extraction and inefficient irrigation practices.

In Australia, there is concern that the interconnection of surface and groundwater have not been accounted for in surface water allocations and the calculation of sustainable groundwater extraction yields. To address this, the National Water Commission is undertaking studies for:

- improving our knowledge of groundwater-surface water connectivity;
- improving the definition of sustainable extraction rates and regimes;
- developing better understanding of the relationship between groundwater and important groundwater-dependent ecosystems (NWC 2008).

Groundwater makes up approximately 17% of Australia's accessible water resources and accounts for over 30% of our total water consumption (NWC 2008). Groundwater aquifers generally provide high quality water that requires little treatment before use. Existing groundwater sources in SEQ are used primarily for municipal purposes and irrigation supplies. Private bores also provide small quantities of water, mainly for garden irrigation. The aquifers on North Stradbroke Island and Bribie Island as well as Moreton Island have been identified by the Queensland government as having usable quantities of groundwater for future use (NRM 2006). However, further extraction is constrained due to the high risk of saltwater intrusion, reduction of groundwater discharge to streams and groundwater dependant ecosystems, and potential damage to significant indigenous sites (QWC 2009).

3.5.1 Biophysical Descriptions of Groundwater

Groundwater is usually extracted from bores drilled into an aquifer (Nevill 2009, p. 2606). The first stage involved in the process of groundwater extraction for urban consumption is the establishment of a borefield. A borefield is a series of bores spaced over an area, so that the drawdown of groundwater caused by pumping is spread out over a large area. Figure 13 shows a typical bore with water being extracted. The aquifer level is drawn down around the bore in what is known as the 'cone of depression'.

Extracted bore water is then pumped to a water treatment plant before distribution. Borewater can contain chemical and microbiological hazards that are potentially harmful to health. These hazards may occur naturally or be due to contamination from mining, industrial or agricultural processes and urban development.

3.5.2 Impacts

A. Extraction Impacts

The extraction of groundwater for agricultural, commercial and domestic use has the potential to cause severe damage to terrestrial and aquatic groundwater dependent eco-systems (Hatton and Evans 1998; Evans and Clifton 2001 in Nevill 2009, p. 2609). A study of the long term impacts of groundwater extraction found that the affects that required attention are:

- Altered and reduced stream flow;
- Land subsidence;
- Lowering of the groundwater table;
- Saltwater intrusion; and
- the draining of acid sulfate soils
  (Zektser, Loaiciga and Wolf 2005; Tularam and Krishna 2009; Cullen 2006).

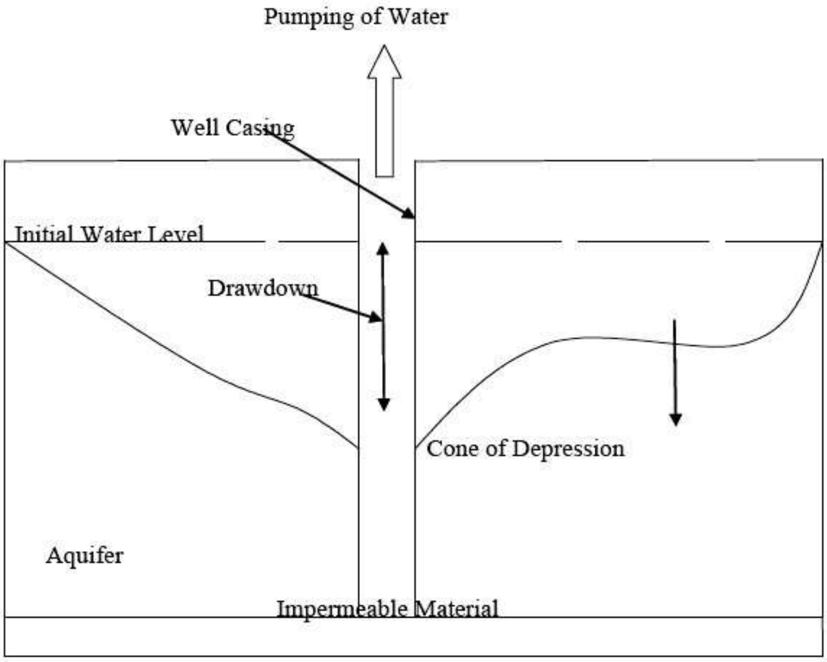


Figure 13: A typical groundwater pumping bore.
Source: Tuluram and Krishna (2009, p.153).

The impacts of sea-water level rises associated with climate change may prove highly damaging exacerbating the impacts identified above (Tuluram and Krishna 2009).

A study of the effects of increased groundwater extraction on the ecosystems of North Stradbroke Island found that there was a reduction in regional water table depth that altered the surface water flow from perennial streams and lowered the level of the groundwater fed lakes impacting on the macrophyte communities in the lake. There were also seawater intrusions into the groundwater recorded as well as changes to pH levels and other physicochemical attributes. The impacts of groundwater extraction are discussed in detail below;

(i) Reduced Stream Flow

There has recently been increased awareness of the importance of considering groundwater and surface water interaction when determining groundwater extraction rates. The flow of water between groundwater and a stream can either be from the stream to the groundwater known as 'a losing stream', or from groundwater into the stream known as 'a gaining stream'. The impact of groundwater extraction on a losing stream is an increased rate of stream leakage. The impact on gaining streams from groundwater extraction is that the inflow to the stream (known as 'base flow') will be reduced. If extraction continues, the gradient may be altered to such an extent that water begins to flow from the stream to the groundwater, becoming a losing stream and essentially being drained (Evans 2001; Candela *et al.* 2009). The impacts of groundwater extraction described above are represented in Figure 14.

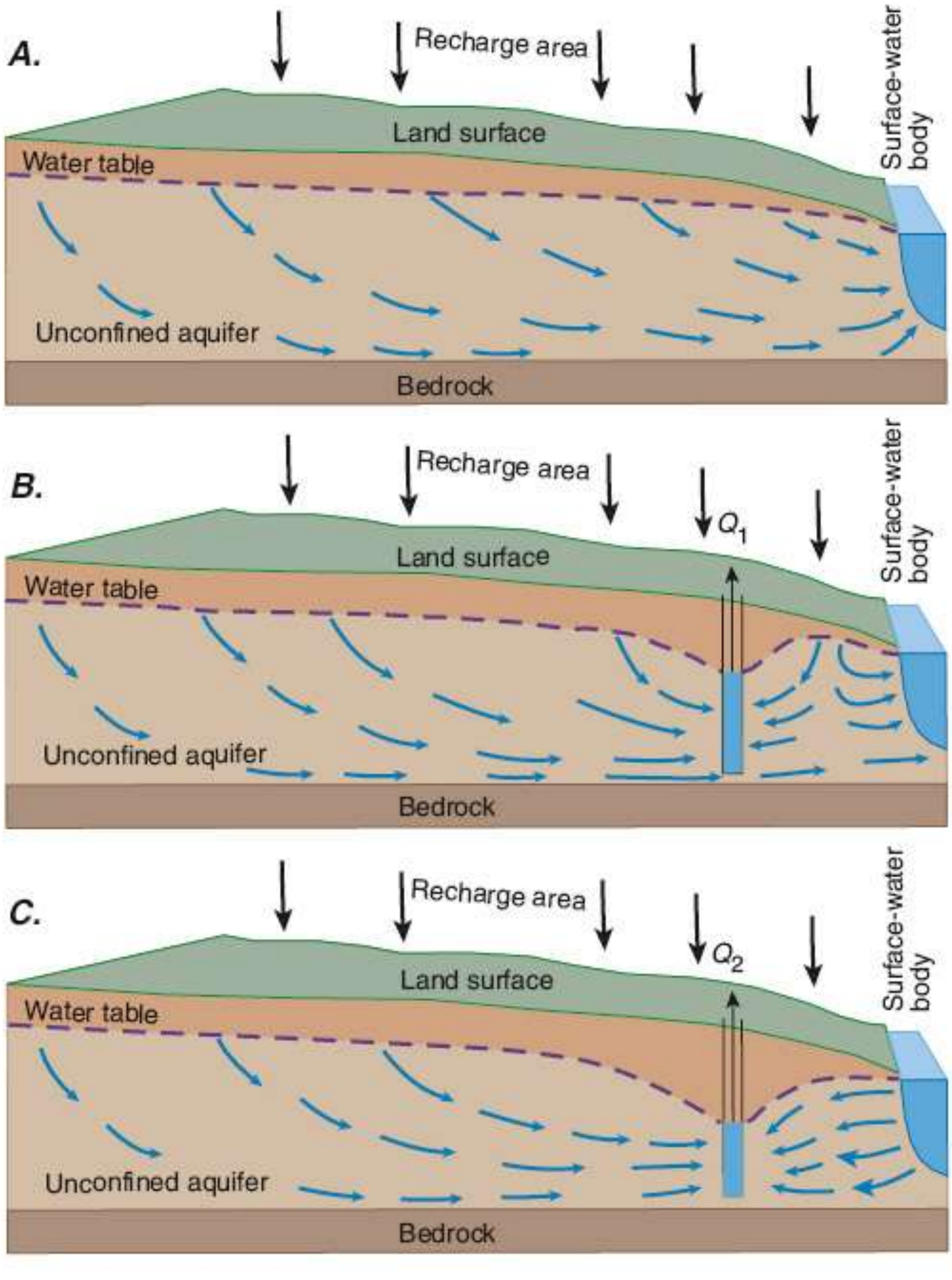


Figure 14: The impact of extraction on groundwater – surface water connectivity.
Source: Masterson and Portnoy (2005, p.11).

(ii) Land Subsidence

Land-surface subsidence is a well-known phenomenon associated with groundwater extraction (Domenico and Schwartz 1997 in Zektser, Loaiciga and Wolf 2005). Subsidence occurs when the hydraulic head in an aquifer declines reducing pore pressure and draining the pore space in an aquifer (Zektser, Loaiciga and Wolf 2005; Tuluram and Krishna 2009, p. 163). Land surface subsidence has been known to cause infrastructure damage to earthen dams, roads, railways and buildings (Zektser, Loaiciga and Wolf 2005; Nevill 2009).

(iii) Lowering of the Groundwater Table

Groundwater pumping causes drawdown locally at the site of the bore, known as the 'cone of depression' and on a regional scale and may cause the lowering of the groundwater table. Another reason for the lowering of the groundwater table is prolonged drought. This has the potential to cause severe damage to both terrestrial and aquatic ecosystems in some cases very conspicuously, in others quite imperceptibly due to the extended period over which the damage occurs (Sophocleous 2002; Nevill 2009). In addition to local depression, groundwater extraction may also lead to a reduction in regional groundwater table depth (Marshall, McGregor and Negus 2006).

Vegetation in semi-arid lands can be severely affected by the lowering of the water table. This is particularly pertinent to phreatophytes, plants that rely on groundwater for subsistence. The depth to which the plant's roots extend is generally less than 5m (Zektser 2000 in Zektser, Loaiciga and Wolf 2005). Therefore, long-term decline of a table can be acutely detrimental to this vegetation. A number of species live within aquifers and groundwater dependent ecosystems. Rare and endemic species that include plants, fish, and karst dwellers who, among others, have seen their populations decline, have become threatened with extinction due to diminished spring flow. (Zektser, Loaiciga and Wolf 2005). The lowering of groundwater levels has lead to the exposure of peat layers to drying and is a potential fire hazard (Marshall, McGregor and Negus 2006).

A study of the Dumaresq River Aquifer on the border of Queensland and New South Wales found that surface water extraction caused the groundwater table to fall by 34 metres. The decrease in groundwater table depth caused the death of terrestrial vegetation over considerable areas and was exacerbated due to drought conditions (Chen 2003 quoted in Nevill 2009). Removal of groundwater from a shallow aquifer may cause an upwelling and inflow of highly mineralised, deep groundwater into overlying fresh aquifers (Zektser, Loaiciga and Wolf 2005).

(iv) Seawater Intrusion

Seawater intrusion occurs in coastal aquifers subjected to groundwater extraction (Tuluram and Krishna 2009, p.153). Groundwater extraction lowers the hydraulic head of the aquifer causing saline water to migrate towards the aquifer. This intrusion of seawater into previously fresh water aquifer causes contamination that is difficult to reverse (Zektser, Loaiciga and Wolf 2005). A study of groundwater extraction in Bundaberg, Queensland found that extraction had caused saltwater intrusions into parts of the aquifer system. The intrusion was located at the sites of high use and was creating a 'saltwater wedge' (Dempster 1994, p.1). Salinisation of groundwater also leads to agricultural as well as environmental problems (Tuluram and Krishna 2009, p.155). Figure 15 demonstrates seawater intrusion caused by groundwater extraction.

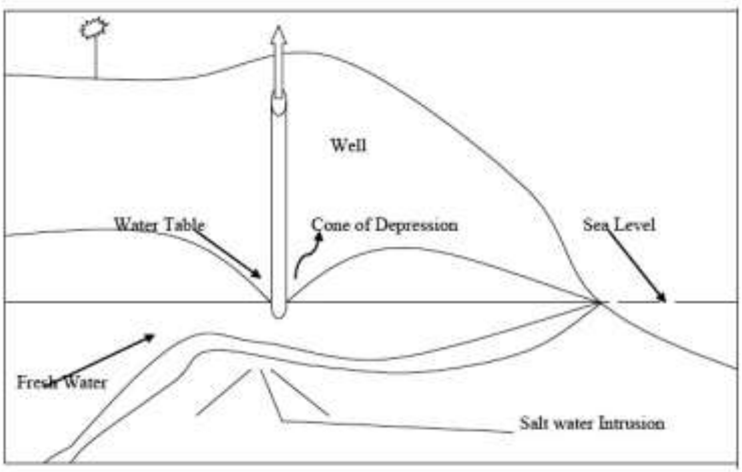


Figure 15: Seawater intrusion into a freshwater aquifer.

Source: Tuluram and Krishna (2009, p.154).

Seawater intrusion is an identified risk on Stradbroke Island. This is primarily due to the uncertainties around the location of the freshwater / saltwater interface and the sustainable aquifer yield (see Figure 16). Saltwater intrusions into freshwater systems may inundate the superlittoral zone (Marshall, McGregor and Negus 2006).

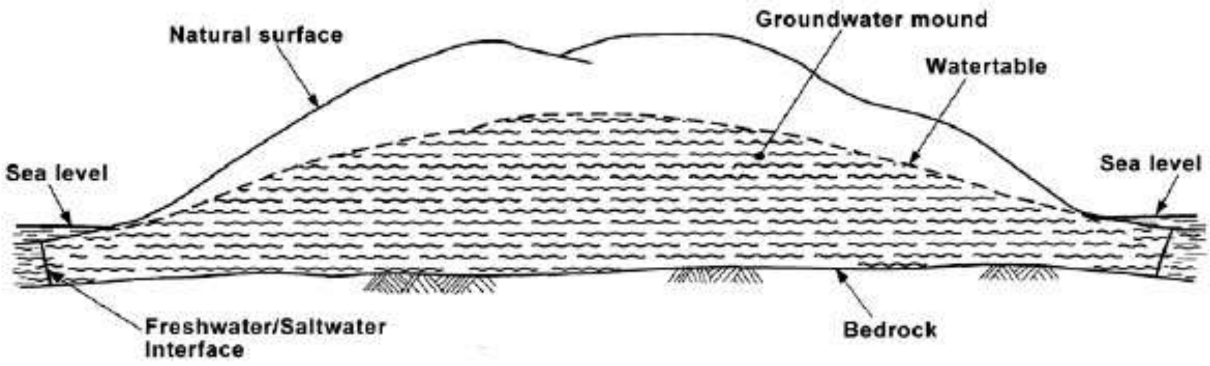


Figure 16: Freshwater aquifer on Stradbroke Island, Queensland.
Source: SIMO (2008, p.2).

(v) Draining of Acid Sulphate Soils

Draining acid sulphate soils, often found in low-lying coastal plains, can result in acidification and pollution of freshwater and estuarine streams (Nevill 2009; Sommer and Horwitz 2001, quoted in Nevill 2009).

(vi) Social and Cultural Impacts

Extraction of water from aquifers may impact on indigenous people’s social, spiritual, and customary uses of water sources fed from groundwater such as springs and wetlands. A study of the Condamine aquifer in the SEQ part of the Murray-Darling Basin demonstrates severe and chronic impairment of indigenous use of water resources. This then restricts accessibility to local traditional custodians in their ability to pass down traditional knowledge and to maintain environmental conditions and spiritual values attached to the sites (White 2010). It has also severely compromised the regions ability to survive during drought periods as the impact s of over-extraction is widening the gap between surface water sites and the groundwater table (White 2010).

The Nyungar of Western Australia see groundwater extraction as impacting on their ability to use their water sources for cultural, spiritual and historical purposes (McDonald, Clodrick and Villiers 2005). Indigenous evidence of the impacts of groundwater extraction includes previous ‘permanent’ natural springs no longer flowing, historic ‘soaks’ drying out, and no food sources at billabongs.

B. Treatment Impacts

Groundwater quality deteriorates through the introduction of contaminants from human and natural activities. The lowering of aquifer levels from groundwater extraction has also led to reductions in groundwater quality (Al-Ibrahim 1991). Groundwater may become acidic at the point of drawdown and potentially exhibit elevated concentrations of sulphates and heavy metals (Appleyard and Cook 2009). Saltwater intrusion is a common threat due to the high density of populations in many coastal regions. Contamination of groundwater is a health risk and may increase the treatment requirements.

Whilst groundwater is generally of a high quality, there are a number of risks associated with the use of groundwater for urban water supplies. The most significant diffuse contaminant of groundwater in Australia is nitrates, due to their adverse effects on people, animals and the environment (Tuluram and

Krishna 2009, p.155). A study of groundwater systems around Brisbane found that they may be susceptible to the effects of increased urban development which can decrease water quality and introduce nutrients from fertilisers and sewage. Other localised risks to groundwater contamination include old landfills, petroleum storage sites and industrial sites.

C. Decommissioning Impacts

There is limited research on decommissioning related to groundwater supply. This is likely to be because the infrastructure used is not significant. If externalities exist they would tend to be associated with the de-commissioning of treatment or perhaps recharge facilities.

3.5.3 The Externality Tables for Groundwater

The complete listing, and short descriptions of major characteristics, of the externalities identified for groundwater are presented in the tables below.

The information is provided in two table formats. The first table (Table 19) is intended as a summary table and is a condensed version showing some key features in symbolic form (see the table key and paragraph below) and the reference source codes. The second version (Table 20) comprises the extended version with some detail about the nature of the externalities as examined in existing research.

Table 19: Main externalities associated with groundwater - Summary table.

Note: positive (+) or negative externality (-); whether impacts tend to occur predominantly downstream (↓), upstream (↑), or within the immediate surrounds of the supply infrastructure (◙).
Reference label numbers are provided at the end of each externality listed. The full reference details are provided in Appendix A.

GROUNDWATER												
LIFE CYCLE OR OPERATIONAL PHASE	**EXTERNALITY TYPE (showing if positive or negative effect, main location and reference source number)** (see Appendix A for reference source code details)											
	Greenhouse Gas Emissions	**Energy**	**Water Quality**	**Nutrients**	**Production**	**Recreation**	**Amenity**	**Health**	**Ecosystem**	**Biodiversity**	**Non-use Values**[1]	**Other** (eg. flood mitigation)
General						-,◙ 284	-,◙ 284		-,↓, ◙ 177, 282			- 283, 176, 280
Collection/extraction					-,↓, ◙ 261, 175				-,↑,↓,◙ 174, 178, 175, 279, 281, 261, 278, 177	-,↑,↓, ◙ 175		
Treatment and Disinfection			- 325	- 325				- 325				
Storage												

1. Non-use values include option, bequest, intrinsic, vicarious and existence values in the total economic value (TEV) scheme.

Table 20: Main externalities associated with groundwater – Existing study details.

Note: positive (+) or negative externality (-); whether impacts tend to occur predominantly downstream (↓), upstream (↑), or within the immediate surrounds of the supply infrastructure (◙). Reference label numbers are provided at the end of each externality listed. The full reference details are provided in Appendix A.

GROUNDWATER	
LIFE CYCLE OR OPERATIONAL PHASE	**EXTERNALITY TYPE, DESCRIPTION (showing if positive or negative effect, main location and reference source number)** (see Appendix A for reference source code details) (see inset table to left for externality type codes)
General	**R and A:** May interrupt the coastal ecosystems of Stradbroke island which are valued highly by surfers (approx. amount spent by surfers on surfing at South Stradbroke Island is $20 000 000). (-, ◙) 284 **E:** acidification and pollution of freshwater and estuarine streams (-,↓, ◙) 177 **E:** Severe damage to terrestrial and aquatic ecosystems (-,↓, ◙) 177 **E:** Overuse may lead to decreasing aquifer levels and reductions in groundwater quality (-,↓, ◙) 282 **O:** People value the independent existence of groundwater for environmental functioning highly (-) 283 **O:** severe and chronic impairment of Indigenous social, spiritual, and customary uses of water resources due to deterioration of the resources and restricted accessibility. This impairment influences the ability of Traditional Custodians to pass down traditional knowledge and to maintain environmental conditions and other important qualities of these sites. (-) 176 **O:** Affects spiritual values of ecosystems which are associated with groundwater, e.g. the Nyungar people see groundwater extraction as a source of cultural, spiritual and historical degradation (-) 280
Collection/Extraction	**P:** May lead to rising water tables, causing water logging, and possible salinisation destruction of agricultural land and community assets. (-,↓, ◙) 261 **P:** Also, groundwater withdrawal may trigger the upwelling and inflow of highly mineralised, deep, groundwater into freshwater aquifers, and induce seawater intrusion into coastal areas. (-, ◙) 175 **E**: Reduction in regional water table depth (-, ◙) 174, 177 **E**: (Stradbroke specific) Reduction of Blue Lake Water Depth; (-, ◙) 174 **E:** (Stradbroke specific) Reduction of surface water flow from Blue Lake to 18 Mile Swamp (-, ◙) 174 **E:** Saltwater intrusion into groundwater (-,↓, ◙) 174 **E:** Changes in surface water flow from perennial streams and ocean discharge (-,↓, ◙) 174 **E:** reductions in stream recharge and possible leakage (-,↓, ◙) 178, 278 **E:** Saltwater intrusion into freshwater systems, Supralittoral zone inundation by saltwater (-,↓, ◙) 174 **E:** Reduction of aquifer seepage on dune escarpment (-, ◙) 174 **E**: Increased regional water table fluctuation, mostly in the form of lowering, (duration of dry spells/timing/etc) (-,↓, ◙) 174, 261 **E:**Changes in pH and other physicochemical attributes (-, ◙) 174 **E:** Exposure of peat layers to drying and fire (-, ◙) 174 **E:** Decreasing river runoff (-,↓, ◙) 175, 281 **E:** Alteration of karst processes (-,↓, ◙) 175 **E:** Draining acid sulphate soils, often found in low-lying coastal plains, can result in acidification and pollution of freshwater and estuarine streams (-, ◙) 177 **E:** Groundwater may become acidic at the point of drawdown and potentially exhibit elevated concentrations of SO42−, Al, Fe, Zn, Cu, Ni and Pb (-, ◙) 279 **E:** Land-surface subsidence along with infrastructure damage (-, ◙) 175, 177 **B**: Rare, endemic, species that include plants fish and karst-dwellers among others may become threatened due to diminished spring flow due to groundwater extraction. (-, ◙) 175 **B:** Groundwater extraction has lowered water tables, negatively impacting habitat for invertebrate species (-, ◙) 175 **B:** lowering of water table negatively impacts native vegetation (-, ◙) 175 **B:** (Stradbroke specific) Alteration of macrophyte habitat in Blue Lake; (-, ◙) 175
Treatment and Disinfection	**WQ:** Risk of contamination stemming from natural sources (e.g. arsenic), old landfills, storage sites and industrial sites (-) 325 **N:** Risk of nitrogen contamination from old landfills and agricultural and industrial sites (-) 325 **H:** Risk of water contamination with various harmful materials (e.g. arsenic) stemming from old landfills, industrial sites and petroleum storage sites (-) 325
Storage	
Use/distribution	
Decommission	

	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

3.6 Greywater

Greywater is domestic wastewater generated from household appliances including dishwashers, clothes washing machines, showers and bathroom and laundry sinks. Water from the toilet is excluded from greywater and is instead referred to as ‘blackwater’. In Queensland, water from the kitchen sink is also excluded due to water quality issues. It is estimated that greywater comprises 60-70% of household water demand, with blackwater comprising the remaining 30%. (Friedler and Hadari 2006, p.222). The Queensland Water Commission (QWC) estimates that a two person house can generate between 60 and 225 litres of greywater per day (QWC 2009).

The QWC recognise the potential for greywater to reduce the impacts of water restrictions, particularly in providing water for gardens during drought periods, as well as providing water for toilet flushing to decrease reliance on potable sources (QWC 2009). The Queensland Government introduced new laws, in March 2006, to broaden the use of greywater. Under this legislation, people are allowed to manually bucket greywater from the laundry and bathroom (excluding the toilet) or to connect a flexible hose to divert it from the washing machine to the garden.

The main concern with greywater reuse in and around the home is the presence of micro-organisms and the human health risks they present. In addition, water from bathrooms and laundry add detergents, bleaches, soaps, sand, perfumes, and shampoos, which may pose environmental threats to soils and eventually runoff into stormwater (Glick, Guggemos and Prakash 2009, p.1). However, the benefits decentralised water supplies provide in terms of water security cement this option’s popularity. Education regarding homeowner operation and maintenance responsibilities and local government regulatory requirements is also occurring to minimise potential health risks.

3.6.1 Biophysical Description of Greywater Reuse

The first stage of the greywater process involves the interception of household wastewater before it enters into the sewage system. In Queensland, greywater can be collected, stored, and used in a number of ways. The simplest system is the collection of greywater via buckets and tubs, which is then used externally for the irrigation of lawns and gardens. Another method of direct use is diversion via a flexible hose connected to the outlet of the water appliances (usually a washing machine) that drains via gravity onto the garden.

More complex systems that require installation by a licensed plumber are those that use diversion devices to divert greywater into a storage vessel and then to a small treatment plant (DERM 2010). An application to the local council is required for more sophisticated systems, and must be installed by a plumber licensed in Queensland to meet Australian standards (QWC 2008). This water can then be used for irrigating lawns and gardens, washing vehicles and outdoor areas, flushing toilets and laundry purposes. Table 21 shows the allowable uses determined by the water quality results of a treatment plant for a household generating less than 3kL.

Simple greywater diversion systems are being installed by many households in SEQ. These diversions generally involve the connection of a diverter pipe to the clothes washer discharge pipe or shower drain for application to gardens (WSAA 2006). Figure 17 illustrates a typical collection and use system for domestic greywater in Queensland.

Table 21: Potential end uses of greywater from a treatment plant generating less than 3 kL per day.

Potential End Uses	Parameter	Effluent Compliance Value
End uses with a high level of human contact, including: • Sanitary flushing • Laundry use (cold water source to washing machines) • Vehicle washing • Path/Wall washdown	Biochemical oxygen demand (BOD5) Total suspended solids (TSS) Thermo-tolerant organisms (org/100ml) pH Turbidity Disinfection	≤10 mg/L ≤10 mg/L <10 6.5 – 8.5 <2 NTU (95%ile) / <5 NTU (maximum) Cl: 0.2 – 1.0 mg/L residual (where used as primary disinfection)
End uses with a medium level of human contact, including: Lawn and garden spray irrigation	Biochemical oxygen demand (BOD5) Total suspended solids (TSS) Thermo-tolerant organisms (org/100ml) pH Turbidity Disinfection	≤20 mg/L ≤30 mg/L <30 6.5 – 8.5 <5 NTU (95%ile) Cl: 0.2 – 1.0 mg/L residual (where used as primary disinfection)
End uses with a low level of human contact, including: • Lawn and Garden manual bucketing, surface broadcasting, sub-surface irrigation	Biochemical oxygen demand (BOD5) Total suspended solids (TSS) Thermo-tolerant organisms (org/100ml) pH Disinfection	≤240 mg/L ≤180 mg/L N/A N/A N/A

Source: DIP (2008a, web page).

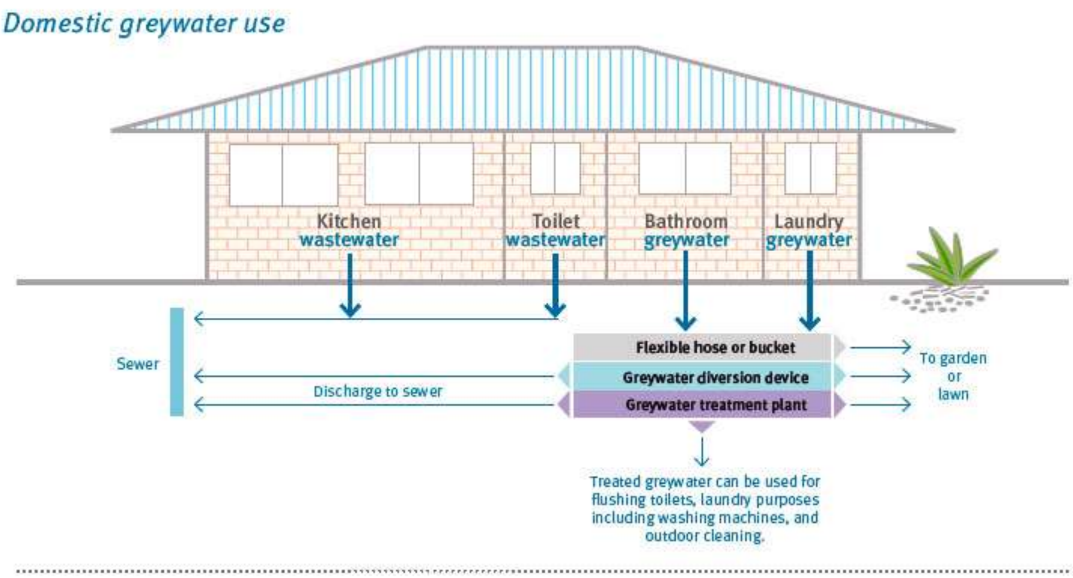


Figure 17: Domestic greywater systems in a household.
Source: DERM (2010, web page).

3.6.2 Impacts

A. General Impacts

The significant benefits of greywater relate to its reliability and affordability for both individuals and the community (Brown 2009). Greywater also has a number of social externalities associated with the ability to maintain gardens, both community and household, through drought conditions and water restrictions (Gordon, Chapman and Blamey 2001). In addition to the social benefits, environmental externalities include the ability of greywater use to off-sets the use of high quality potable supply hence reducing the amount of wastewater requiring treatment and disposal, helping to reduce pollution levels in rivers and oceans (Jeppesen 1996; Friedler and Harari 2006; Al-Jayyousi 2003; Christova-Boal, Lechte and Shipton 1995). Current estimates suggest that 30% of Queenslanders with gardens use greywater produced on-site (DERM 2009 in DERM 2010).

On-site greywater reuse may also be an empowering experience for people and promote self-reliance and the principles of sustainability (Parkinson and Tayler 2003, p.75). However, there are a number of council requirements for the effective management of greywater in SEQ. Councils assess and approve the applications for greywater use to ensure that all environmental and health issues on the site are managed. Councils also monitor the greywater systems to ensure compliance and communicate with homeowners to ensure they understand their responsibilities and know how to operate the systems effectively (DIP 2008b).

Table 22 provides an overview of the costs and benefits of greywater systems. Whilst decentralised systems transfer operation and maintenance costs to the individual households, the costs associated with greywater use are relatively small. For greywater systems that store and treat water, the costs include; capital, operation, and maintenance outgoings (Friedler and Hadari 2006, p.223; and Christova-Boal, Lechte and Shipton 1995).

Table 22: Greywater reuse – costs and benefits to individual consumers and the general public.

Benefits	Costs
Individual consumer: • Money saving Water bill Sewage bill	• Network separation – Collection: grey, black – Supply: potable, treated greywater • Greywater treatment system – Capital costs – Operation and maintenance costs – Monitoring costs • Treated greywater conveyance – Energy
General public: • Water resources – Development of new resources can be postponed • Water abstraction – Less energy • Water treatment – Less energy – Fewer chemicals – Existing plants: enlargement can be postponed – Future plants: smaller • Water conveyance and distribution – Less energy – Existing systems: enlargement can be postponed – New systems: smaller • Wastewater collection – Less energy (force mains) – Existing systems: enlargement can be postponed – New systems: smaller • Wastewater treatment plants (WWTP) – Lower pollutants loads (degradable pollutants) – Less energy? – Fewer chemicals Existing – WWTP: enlargement can be postponed? New WWTP: smaller?	• Wastewater collection – Lower flows, more blockages? • Wastewater treatment plants – Higher pollutants concentration (less dilution)

Source: Adapted from Friedler and Hadari (2006, p.223).

Since domestic greywater production is greater that its consumption, it has been suggested that sources should be limited to ‘light’ greywater streams such as from baths, showers and washbasins. This would then be helping reduce centralised treatment costs, and at the same time reducing potential health risks to the individual (Friedler and Hadari 2006, p.222).

The use of greywater to reduce the demand for potable water for toilet flushing and garden irrigation has the potential to defer water supply augmentations (Christova-Boal, Lechte and Shipton 1995; Friedler and Hadari 2006). Greywater can also significantly reduce the amount of wastewater treatment required, thereby lowering costs and reducing pollution levels to receiving waters (Christova-Boal, Lechte and Shipton 1995). Similarly, any future enlargement or upgrade of wastewater treatment plants can be postponed (Friedler and Hadari 2006). This reduction in water to the sewer decreases the volume of treated effluent discharged to waterways, therefore reducing the ecological impacts.

Studies show that public acceptance of the principle of greywater reuse is high for low-contact uses (Jeppesen 1996, p.311). Results from a study in Melbourne indicated around 40% of residents were interested in reusing bathroom or laundry greywater for garden watering, but only 11% in using the water for toilet flushing (Christova-Boal, Lechte and Shipton 1995).

B. Collection and Storage Impacts

The collection of greywater is relatively low cost, involving minimal plumbing augmentation. Costs increase with the complexity of the system, for example, if the collected greywater is stored. Storage of greywater may significantly improve water quality due to the settling of organic matter, however, if water is stored for a period of greater than twenty four hours this can lead to problems. Over the 24-hour benchmark, oxygen levels become depleted due to microorganism growth, causing the greywater to turn septic, leading to odour and aesthetic problems (Dixon, Butler and Fewkes 1999; Eriksson *et al.* 2002). Stored water also provides a site for the breeding of mosquitoes (Jeppesen 1996). When the immediate use of greywater is not practical it is recommended that it be diverted to the sewerage system, for example, during periods of wet weather (DIP 2008a).

C. Treatment/Disinfection Impacts

Whilst most households choose to divert greywater directly onto the garden, a number of systems that treat greywater are available. Greywater treatment systems generally vary for single households and multiple dwellings. The federal governments ‘National Rainwater and Greywater Initiative’ defines household greywater treatment systems as usually including primary treatment in the form of a grease trap and coarse filter, and secondary aerobic treatment and disinfection (DEWHA 2010).

Treatment of greywater is expensive and can be time consuming on an individual household basis (Jeppesen 1996, p.312). The costs for the individuals include the capital cost of the unit, operation and maintenance costs, monitoring costs and distribution or pumping costs (Friedler and Hadari 2006). Ensuring that the units receive regular maintenance and treat water to a specified level is a difficulty faced by local governments (Jeppesen 1996, p.312). Many people lack the appropriate household configurations, time, and inclination needed to manage simple systems; more engineered systems require higher expense and maintenance (WSAA 2006; DIP 2008). More technical systems can also require a higher level of skill to operate (PMSEIC 2003).

Greywater treatment plants for apartments or multiple dwelling commonly use a rotary biological contactor (RBC) in conjunction with physicochemical treatment (sand filtration and disinfection). These pilot plants, shown in Figure 18, produce effluent of excellent quality, meet urban reuse quality regulations, and are efficient in TSS turbidity and biochemical oxygen demand (BOD) removal (Friedler *et al.* 2004). These findings are supported by a study in Germany of a RBC built for 70 apartments that has been operating for ten years (Nolde 1999). Treatment at the household and multiple dwelling scale is shown to be less energy intensive and requires fewer chemicals than major treatment plants (Friedler and Harai 2006). Currently, there are few data on the energy requirements of greywater systems.

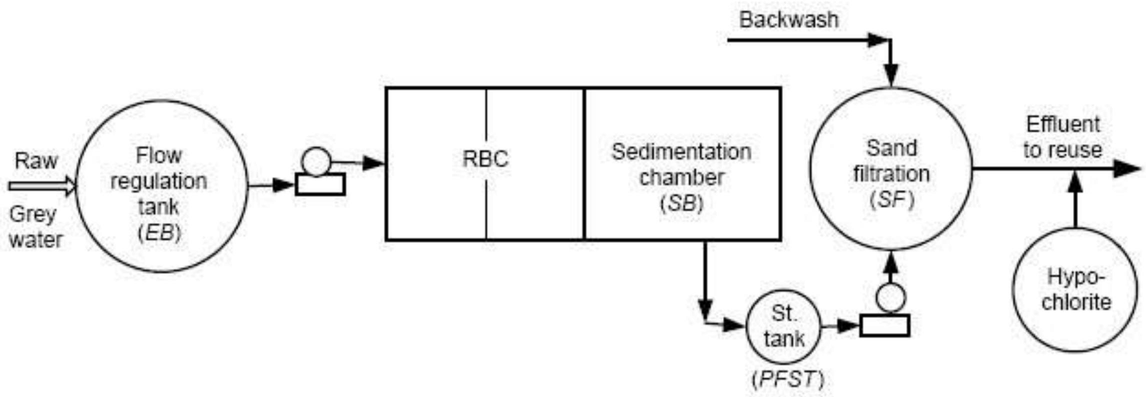


Figure 18: Schematic layout of a greywater pilot plant.

Source: Friedler, Kovalio and Galil (2005, p.189)

D. Use/Distribution Impacts

Whilst generally considered a beneficial water resource, there are a number of impacts on health, the environment, and productivity associated with greywater.

(i) Health

Greywater contains chemicals and microorganisms that may be harmful to public health and the environment (Jeppesen 1996, p.311). The chemical and microbiological composition of greywater may vary depending on the source of the wastewater but some typical characteristics of greywater are listed in Table 23. Due to the exclusion of water from the toilet, greywater has significantly lower bacteria, viruses, and pathogens than sewage, however similar levels of heavy metals are present (Eriksson *et al.* 2002, p.85). Kitchen wastewater may contain fats, grease, food waste, and cleaning products. It is illegal to use kitchen wastewater in sewered areas in Queensland due to health concerns and environmental impacts.

Table 23: Physico-chemical and microbiological characteristics of grey wastewater.

Concentration (mg/ℓ)	Bathroom (BO90)	Bathroom (literature)*
Temperature (°C)	21.6-28.2	29
pH	7.6-8.6	6.4-8.1
COD	77-240	100-633
BOD	26-130	50-300
SS	7-207	40-120
NH_4-N	0.02-0.42	<0.1-15
NO_3-N	<0.02-0.26	0.28-6.3
Tot-N	3.6-6.4	5-17
PO_4-P	na	0.9-49
Tot-P	0.28-0.779	0.11-2
Ca	99-100	3.5-7.9
K	5.9-7.4	1.5-5.2
Mg	20.8-23.0	1.4-2.3
Na	44.7-98.5	7.4-18
Total bacterial pop. (per 100 mℓ)	4×10^7-1.5×10^8	107-3×10^8
Total coliforms (per 100 mℓ)	6×10^3-3.2×10^5	103-2.4×10^7
E. Coli (per 100 mℓ)	<100-2800	na

*Eriksson et al., 2002a
na: not analysed

Source: Eriksson *et al.* (2003, p.137).

There is a low risk of disease transfer through trace faecal coliforms and other microorganisms present in greywater (Ottoson and Stenstrom 2003). The common diseases related to greywater in Australia are listed below in Table 24.

Table 24: Incidence (per 100, 000) for a range of potential greywater-borne diseases by State.

Disease	NT	TAS	WA	NSW	QLD	SA	ACT	VIC
Campylobacteriosis	136.3	144.5	99.7	--	106.1	169.4	123	80.9
Cryptosporidiosis	52.1	7.5	28.9	7.9	10.3	28.3	2.6	13.4
Salmonellosis	246.1	45.4	46.9	37.1	56.6	55.5	32.4	45.4
Typhoid	1.4	0.6	0.4	0.5	0.1	0.4	0.4	0
Cholera	0	0	0	0	0	0.1	0	0
Shigellosis	81	0.6	4.9	1	2.1	4.2	0	2.9
Legionellosis	0.4	0.6	3.9	1.5	1.2	1.1	1.2	1.5
STEC, VTEC	1.4	0	0.1	0.3	0.6	2.6	0.3	0.5
Hepatitis A	2.3	0.6	1	0.9	0.7	0.3	0.6	0.8
Hepatitis E	0	0	0	0.1	0.1	0	0.3	0.1
Percentage of population collecting greywater	**32.3%**	**37.0%**	**43.2%**	**46.7%**	**54.1%**	**54.3%**	**63.1%**	**71.7%**

Source: Brown (2009, p.6).

The pathways for the spread of disease from domestic greywater is in the form of aerosols or splashing of water from toilets flushed with greywater. Exposure to either forms, resulting from inhaling or skin exposure, can be dangerous, however, the risk can be minimised by disinfecting greywater or by closing the lid of the toilet prior to flushing (Eriksson *et al.* 2002, p.86). Based on the exposure pathways developed, it can be concluded that subsurface irrigation with greywater presents a low health risk as it involves fewer exposure pathways and minimises the opportunity for direct human contact. Soil and well maintained grass provide a barrier to the risk of exposure (Christova-Boal, Lechte and Shipton 1995).

Studies of treated greywater quality have found that the level of organisms present have exceeded water quality parameters on a number of occasions and are thought to be caused by operator negligence (Leonard and Kikkert 2006 in Brown 2009). However, currently no examples of illness have been recorded in the literature reviewed and whilst there may be unrecorded cases of illness, it provides some confidence in the use of greywater. It is hypothesised that, despite the microorganisms present in the water, the risk of illness is low because of:

- variation in composition of greywater;
- if greywater is used internally for toilet flushing, then savings are estimated to be between 40-60% per household;
- restricting the water sources (ie, no blackwater) reduces potential pathogen input to the system by 99.9% and avoiding kitchen wastewater reduces this further (Ottosson 2004);
- indicators over-estimate the likelihood of pathogen presence by a large factor (approximately 1,000 times) in greywater due to multiplication of indicators and die-off of pathogens (WHO 2006); and
- restricting end uses of the greywater to low-contact activities limits the opportunity for pathogens to exit the system in such a way as to infect others.

In addition to pathogens, harmful chemicals may be present in greywater. Chemicals that have been identified in greywater include: fragrances like citronellol, hexyl cinnamic aldehyde and menthol; preservatives like citric acid; and triclosan. Measurements also revealed the presence of unwanted and unexpected compounds like drugs and pesticides, as well as chemicals not directly deriving from ordinary household use or personal care products, eg, flame-retardants (Casanova, Gerba and Karpiscak 2001) The information regarding the content of xenobiotic organic compounds (XOCs) found in greywater is limited. One study identified the potential for nine hundred different XOCs to be present in grey wastewater using the tables of contents on common household cleaning products (Eriksson *et al.* 2002, p.85).

An additional potential health impact is due to the increased greywater supplies leading to excess water use by householders in the garden. This can result in an increased settling of water creating mosquito breeding sites leading to an increased vector breeding habitat (Jeppesen 1996, p.313). Mosquitoes are vectors for various severe illnesses such as Dengue Fever, malaria, and Ross River Fever.

(ii) Ecosystem

The presence of household chemicals in greywater has the potential to damage soil and plant life (Howard *et al.* 2005, p6). Greywater use requires careful selection of detergents to minimise environmental risks (WSAA 2006). Because of the household chemicals in greywater, it typically has a high pH, high sodium adsorption ration (SAR) and moderately high salinity. The long-term use of untreated laundry greywater may in fact reduce salt contamination of groundwater but predispose soils to future environmental hazards from excess sodium accumulation. Sodium is not used in plants as readily as nitrogen and phosphorus and will accumulate as the plants uptake the water and nutrients, leading to increased clay dispersion and unstable soil structure (Howard *et al.* 2005, p.52). A number of studies on the impacts of greywater use for irrigation and its impact on soils suggested that surfactant accumulation can also alter soil structure and create water-repellent soils, thereby affecting the soils flow patterns (Wiel-Shafran *et al.* 2006, p.348; Howard *et al.* 2005).

The unstable soil structure and clay dispersion caused by the chemicals in greywater could potentially lead to a reduced infiltration rate of rain, water logging if soils are wet, poor soil aeration, and finally hard-setting when soils are dry. The consequence of this is structural degradation resulting in poor plant growth and germination (Travis Weisbrod and Gross 2008; Wiel-Shafran *et al.* 2006; Howard *et al.* 2005). Application of water with a high pH will drastically reduce the growth of plants adapted to acidic conditions; such plants include azaleas and blue couch (Howard *et al.* 2005, p.52).

Another component of greywater quality reduction is the high loading of oil and grease that may be present, particularly if kitchen wastewater is used. Oil and grease can accumulated in soils, leading to a significant reduction in the soils ability to transmit water. This may cause increased runoff which may encourage the runoff of chemicals from the soil areas. The reduced infiltration can then be damaging for plant growth (Travis, Weisbrod and Gross 2008, p.73). It is recommended that residential gardens close to streams or shallow water tables should not be irrigated with greywater to avoid possible pollution of unconfined aquifers and streams (Misra and Sivongxay 2009, p.60; Christova-Boal, Lechte and Shipton 1995).

(iii) Productivity

Whilst there are potential health risks in using wastewater there are also benefits of having an increased supply of water and through using the nutrients present in greywater. Nutrients such as phosphorus found in household detergents may be utilised by plants to enhance growth (Al-Jayyousi 2003, p.181). The re-use of waste can increase local agricultural productivity resulting in increased revenue for local producers (Parkinson and Tayler 2003, p.82).

A study into the impact of greywater for irrigation of silverbeet showed no significant effects on plant biomass and no significant impacts on the nitrogen and phosphorus content of the soil after the plant harvest. There was, however, a significant increase in soil pH and EC with 100% greywater irrigation. Alternating the irrigation of silverbeet with potable water and greywater had pH and EC levels similar to that of 100% irrigation with potable water. Therefore, irrigating alternately with potable water and greywater has the potential to reduce some of the soil health risks associated with the reuse of greywater (Pinto, Maheshwari and Grewal 2009, p.1).

(iv) Social

The social impacts of greywater use relate to cultural perceptions of what is appropriate water use. A study into water reuse, focused specifically on the acceptance of greywater reuse by the Maori in New Zealand, reveals the need for the incorporation of multiple knowledge systems into the water management paradigm. Water and water bodies such as rivers, lakes and wetlands are considered to have their own ‘mauri’, or spirit. Recycling is a concept recognised and practiced by Maori; however the importance of mauri in recycled water greatly influences how it can be used. Furthermore, recycling of waters in a culturally consistent manner can only be achieved by returning the water to the ground. Therefore out-of-catchment transfer or disposing of wastewater or stormwater in rivers is a serious concern (Morgan 2006). This example highlights the social and cultural implications of greywater reuse for many groups and the need for incorporating other cultural values into water management schemes.

E. Decommissioning Impacts

This stage is of minimal relevance to this option given limited infrastructure requirements.

3.6.3 The Externality Tables for Greywater

The complete listing, and short descriptions of major characteristics, of the externalities identified for greywater are presented in the tables below.

The information is provided in two table formats. The first table (Table 25) is intended as a summary table and is a condensed version showing some key features in symbolic form (see the table key and paragraph below) and the reference source codes. The second version (Table 26) comprises the extended version with some detail about the nature of the externalities as examined in existing research.

Table 25: Main externalities associated with greywater - Summary table.

Note: positive (+) or negative externality (-); whether impacts tend to occur predominantly downstream (↓), upstream (↑), or within the immediate surrounds of the supply infrastructure (◙).

GREYWATER												
LIFE CYCLE OR OPERATIONAL PHASE	**EXTERNALITY TYPE (showing if positive or negative effect, main location and reference source number)** (see Appendix A for reference source code details)											
	Greenhouse Gas Emissions	**Energy**	**Water Quality**	**Nutrients**	**Production**	**Recreation**	**Amenity**	**Health**	**Ecosystem**	**Biodiversity**	**Non-use Values**[1]	**Other** (eg. flood mitigation)
General		**(+)** 44	**(+,↓, ◙)** 44		**(+, -, ↓, ◙)** 44, 214, 215		**(-, ◙)** 181	**(-,↓, ◙)** 123, 181, 182	**(+,↓, ◙)** 44, 219, 213		**(+, -, ◙)** 44, 183	**(-, +)** 155, 181, 44, 216, 122, 184
Collection/Storage			**(-,+,↓,◙)** 217 188				**(-, +, ◙)** 188	**(-,↓,◙)** 181, 217, 182	**(-,↓, ◙)** 217			**(-)** 145
Treatment and Disinfection												**(-, +, ◙)** 181, 216
Use		**(+)** 44			**(-, +, ◙)** 168, 214, 215, 187		**(+, ◙)** 218	**(-,↓, ◙)** 145, 182, 123	**(-, +, ↓, ◙)** 145, 185, 216, 44, 214, 168, 187			**(-)** 155
Decommissioning												

1. Non-use values include option, bequest, intrinsic, vicarious and existence values in the total economic value (TEV) scheme.

Table 26: Main externalities associated with greywater – Existing study details.

Note: positive (+) or negative externality (-); whether impacts tend to occur predominantly downstream (↓), upstream (↑), or within the immediate surrounds of the supply infrastructure (◙).
Reference label numbers are provided at the end of each externality listed. The full reference details are provided in Appendix A.

<table>
<tr><th colspan="2">GREYWATER</th></tr>
<tr><th>LIFE CYCLE OR OPERATIONAL PHASE</th><th>EXTERNALITY TYPE, DESCRIPTION (showing if positive or negative effect, main location and reference source number)
(see Appendix A for reference source code details) (see inset table to left for externality type codes)</th></tr>
<tr><td>General
<table><tr><th></th><th>Externality Type Codes =></th></tr><tr><td>GHG</td><td>Greenhouse gas emissions</td></tr><tr><td>En</td><td>Energy</td></tr><tr><td>WQ</td><td>Water Quality</td></tr><tr><td>N</td><td>Nutrients</td></tr><tr><td>P</td><td>Production values</td></tr><tr><td>R</td><td>Recreation values</td></tr><tr><td>A</td><td>Amenity values</td></tr><tr><td>H</td><td>Health values</td></tr><tr><td>E</td><td>Ecosystem values</td></tr><tr><td>B</td><td>Biodiversity values</td></tr><tr><td>NU</td><td>Non-use values</td></tr><tr><td>O</td><td>Other</td></tr></table></td><td>En: Less energy required in water treatment, distribution and collection (+) 44
WQ and E.: Lowers pollutant loads and less chemicals required throughout treatment processes (+,↓, ◙) 44
P: Can postpone building large-scale water infrastructure (+,↓) 44
P: re-use of wastewater can increase local agricultural productivity, resulting in increased revenue for local producers. (+, ◙) 215
P: Altering of soil structure (-, ◙) 214 A: May emit noxious odours (-, ◙) 181
H: Some risk of disease transfer, through trace faecal coliforms or other micro-organisms in the water (-, ◙) 123, 182
H: Greywater does contain chemicals and microorganisms that can be harmful to public health and the environment (-, ↓, ◙) 181
E: Significant fresh water savings (+,↓, ◙) 213 NU : 'Green' image may value-add (+) 44
E: Reduction of effluent discharge to waterways, therefore Reducing the ecological impacts of nutrients or other pollutants (+,↓, ◙) 219
NU: May offend cultural or religious sensitivities (-) 183
O: Requires the careful selection of detergents etc to minimise health and environmental risks, e.g. avoiding excessive salts (-) 155
O: Many people lack the appropriate household block circumstances/time and inclination to manage involved simple systems and more engineered systems require higher expense and maintenance (-) 155, 184 O: Reductions in household water usage by 30 – 50% and therefore cuts down on water bills (+) 181, 44, 122
O: Should uptake be large enough there will be a postponing of further water resource infrastructure required (+) 44
O: Defer the cost of water supply augmentation (+) 216</td></tr>
<tr><td>Collection/Storage</td><td>WQ, H, and E: greywater can contain fragrances (like citronella, hexyl cinnamic aldehyde and menthol), preservatives (e.g. citric acid and triclosan) and unwanted and unexpected compounds like drugs and pesticides, as well as chemicals not directly deriving from household chemicals or personal care products, e.g. flame-retardants. (-, ↓, ◙) 217
WQ. and A: Storing grey water for 24 h may significantly improve water quality through rapid settlement of organic particles, however, storage beyond 48 h leads to depleted DO levels and potential aesthetic problems. (-, +, ◙) 188
H: May affect mosquito populations (-, ◙) 181
H: Growth within the system may provide a source for micro-organisms and some chemicals (-, ◙) 182
O: Well managed systems can require skill and commitment from the household (-) 145</td></tr>
<tr><td>Treatment and Disinfection</td><td>O: Treatment of greywater to make it safe for human contact is expensive to achieve on an individual household basis. It is also difficult to ensure that treatment systems are maintained (-, ◙) 181 O: Lowers community wastewater treatment costs (+, ◙) 216</td></tr>
<tr><td>Use</td><td>En: Energy savings (+) 44 En: less energy involved in distribution (+) 44 En, E: Less energy and chemicals required at major treatment plants (+) 44
P and E: may lead to a significant reduction in the soils ability to transmit water which can lead to water runoff and/or finger flow through the soil profile, both of which can exacerbate the migration of contaminants vertically or horizontally from the irrigated soil. Reduced water movement can also be detrimental to water availability for plant growth. (-,↓,◙) 168, 187
P and E: soil structural degradation may lead to poor plant growth and germination. (-, ◙) 214
P: wastewater can increase agricultural productivity and contribute to the livelihoods of peri-urban communities AND may also be re-used for aquaculture (+, ◙) 215
A: Allows for maintenance of gardens, both community and household, throughout drought conditions and water restrictions (+, ◙) 218
H and E: Greywater must be diverted to sewer when garden water isn't required. If this doesn't occur and water runs off household properties there may be significant public health and environmental problems arise. (-, ◙) 145
H: Potential for public health concern as greywater has been shown to contain high levels of faecal micro-organisms, though risk is minimal (-, ◙) 145
H: introduce a high rotavirus risk (-, ◙) 123
H: If used for toilet flushing, risk that micro-organisms in the water will be spread in the form of aerosols that are generated as the toilets are flushed (-, ◙) 182
E: Long-term use of untreated laundry greywater may predispose soils to future environmental hazards from excess sodium accumulation (-, ◙) 185
E: Reduction in pollutant levels into receiving waters (+,↓,◙) 216
E: If greywater is used by residential gardens close to streams or shallow water tables it may create pollution of unconfined aquifers and streams. (+,↓,◙) 216
O: expensive to install and maintain more sophisticated treatment systems (-) 155 O: Significant household plumbing may be required (-) 155
O: Problems can occur through pipe blockage due to excess hair, lint etc (-) 155
O: expensive to install and maintain more sophisticated treatment systems (-) 155 O: Significant household plumbing may be required (-) 155</td></tr>
<tr><td>Decommissioning</td><td></td></tr>
</table>

3.7 Rainwater Tanks

Having been around for over three thousand years, rainwater harvesting has proven to be a reliable strategy adopted by the human species in response to climatic extremes (Pandey, Gupta and Anderson 2003, p.46; Tam, Tam and Zeng 2009, p.178). With extreme weather patterns predicted to increase due to climate change, rainwater tanks demonstrate high levels of promise in alleviating the impacts of water scarcity (Cheng, Liao and Lee 2006, p.209). Already, rainwater tanks are becoming highly valued within our community, as they provide both personal and community benefits (Gardiner 2009, p.151).

Currently, rainwater tanks are widely used in Australia, especially in rural areas. Around 16 - 17% of all households currently have rainwater tanks (figures given are for 1994 – 2001) (Tam, Tam and Zeng 2009, p.178). At all levels of government, there has been a funding push towards the use of rainwater tanks in response to the drought conditions occurring throughout Australia. For example, the Commonwealth Department of Environment, Water, Heritage and the Arts (DEWHA), established a $250 million fund to offer rebates for anyone wishing to install a water tank (Retamal *et al.* 2009, p.7). Given, that 73% of houses in Australia are compatible to the installation of rainwater tank systems; the prevalence of rainwater tanks is likely to increase in the future (Tam, Tam and Zeng 2009, p.179).

3.7.1 Biophysical Description of Rainwater Tanks

The supply of water from a rainwater tank involves collecting water directly from a non-trafficable roof into a rainwater tank (or equivalent holding device installed onsite), which is usually close to the roof of the dwelling used for water collection (Figure 19). There are three common elements to all rainwater tank systems:

i. Catchment surface off which rainwater is collected (eg, roof);
ii. Storage reservoir (the tank itself); and
iii. A delivery system which transports the water between the stages of collection and use (pumps and pipes) (Tam, Tam and Zeng 2009, p.180).

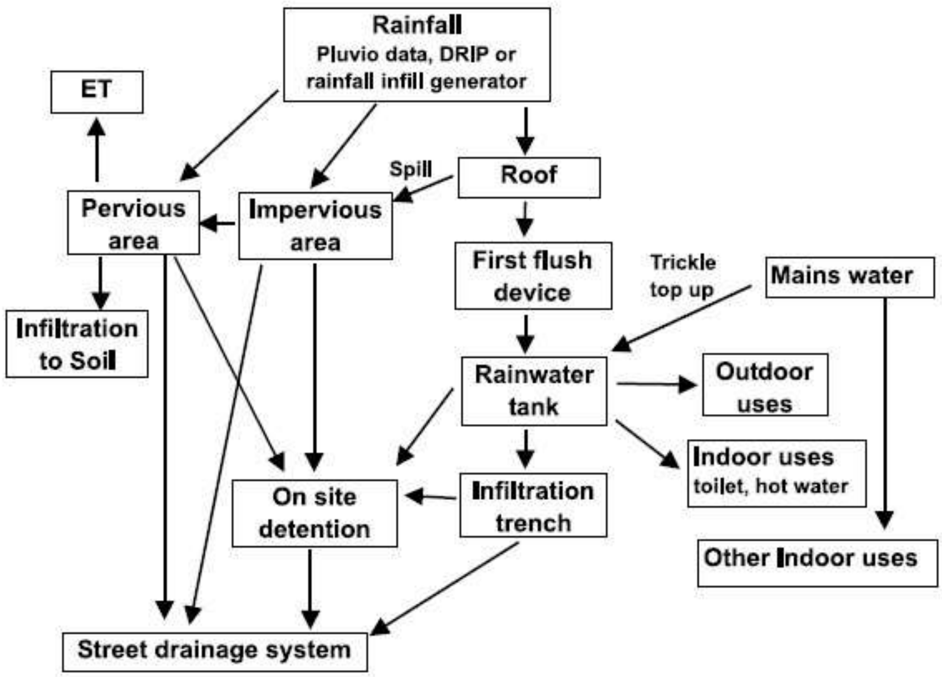


Figure 19: Household water system use.
Source: Coombes *et al.* (2002, p.311)

A study of Sydney's new houses revealed that the most common size of tank was 2 to 3 kL followed by 4 to 5 kL (Retamal *et al.* 2009, p.21).

Under the Queensland Development Code MP 4.2 (QDC 4.2), all Class 1 dwellings constructed after 2007 in SEQ are required to save 70 kL of mains water per year. One acceptable solution for achieving this reduction in mains water use is through the installation of a 5 kL rainwater tank connected to 100 m^2 roof area and plumbed to the washing machine cold water tap, toilets and at least one external tap. While this was the typical inclusion with new houses, other options are available including: a greywater treatment plant; communal rainwater tanks; dual reticulation of recycled water or treated stormwater; or a combination of these. This mandate has resulted in an increase in tank installations, such that, at present, approximately 40% of houses in the SEQ region have one or more rainwater tanks (Gardiner 2009).

For residential dwellings, water from the tank is most commonly used for irrigation or for other uses around the house such as car washing (Gardiner 2009). Alternatively, a pump is connected to the tank allowing greater distribution of the water around the garden or connection to internal plumbing such as the toilet. The latter option is described by Figure 20. Some existing publications suggest that tanks can only create significant water saving when they are continually drawn from, as occurs when they are connected to the domestic plumbing (eg, toilet flushing and other non-potable household uses) (Collins 2008, p.116).

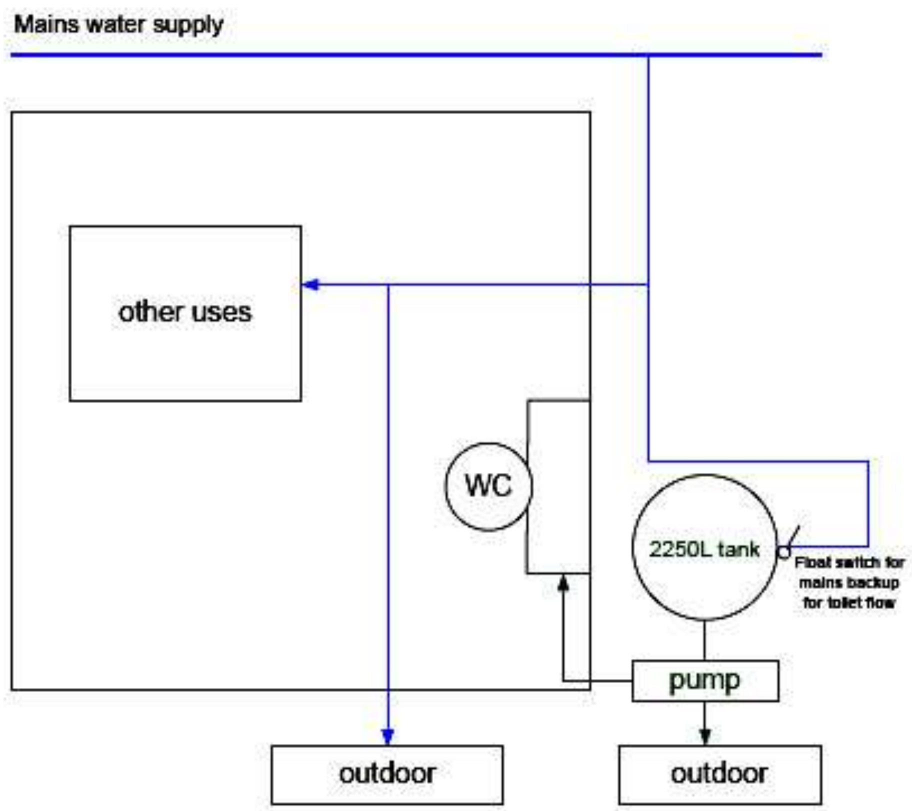


Figure 20: Rainwater tanks used for combined outdoor and internal plumbing to the toilet.
Source: Hallmann, Grant and Alsop (2003, p.29).

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

- have a minimum storage capacity of at least 5000 litres for detached class 1 buildings (houses) or 3000 litres for a non-detached class 1 building (townhouses, terrace houses);

- have a roof catchment area of at least one half of the total roof area or 100 m^2, 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.

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.

3.7.2 Impacts

A. General Impacts

Rainwater tanks offer significant financial, social and environmental benefits; including the potential to reduce reliance on mains water use by up to 50% (Hallmann, Grant and Alsop 2003). The estimates of individual financial savings and rainwater tank yields are highly variable and controversial, as are the potential health risks from drinking rainwater.

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 are greatly variable. Below is a short list compiling some of the existing cost estimations for water tank's financial impacts on individuals:

- Levelised costs range *"from $0.62 to $2.34 per kl and from $0.58 to $2.19 per kl for both outdoor and indoor use and for outdoor use only respectively across different conditions"* (Tam, Tam and Zeng 2009, p.185) (refer to Table 27);
- It has been suggested that due to high rainfall the costs of rainwater tank water in Brisbane, Gold Coast and Sydney is lower than other alternative water supply options, indicating annual savings which range from *"$3 to $223 per year and from $0 to $240 per year for using rainwater both outdoor and indoor, and for outdoor use only respectively in different conditions"* (Tam, Tam and Zeng 2009, p.185) (refer to Table 27);
- Cost to install a rainwater tank of $2185 per dwelling (Coombes *et al.* 2002, p.318);
- Maintenance costs of $0.05 per kL of rainwater used (Coombes *et al.* 2002, p.318);
- Rainwater tank usage in new developments or redevelopments is able to create a saving of $210 – $959 on construction costs per dwelling due to the reduced requirement for stormwater infrastructure;
- Assuming a useful life of 50 years (which is disputed and is considered an optimistic figure) the replacement cost is $864 (Coombes *et al.* 2002);
- Pump replacement cost is $200 with a useful life of 10 years (Coombes *et al.* 2002);
- In addition, the use of rainwater can significantly reduce household mains use. The householder installing a rainwater tank may find significant economic savings from reduced need to purchase mains water (Coombes and Kuczera 2003, p.1).

Table 27: Annual cost saving using rainwater against alternative water sources (for outdoor use only).

City	Annual cost saving from rainwater ($/year)								
	Roof catchment area								
	100 m²			150 m²			200 m²		
	2 kl	5 kl	10 kl	2 kl	5 kl	10 kl	2 kl	5 kl	10 kl
Gold Coast	83	112	102	146	191	176	189	240	229
Brisbane	33	36	34	0	4	−5	22	29	21
Melbourne	−101	−91	−33	−105	−94	−39	−92	−77	−20
Sydney	65	86	77	111	144	132	143	181	172
Adelaide	−93	−109	−126	−132	−151	−174	−125	−143	−165
Perth	−54	−64	−76	−79	−88	−105	−63	−71	−87
Canberra	−83	−81	−101	−75	−67	−89	−59	−50	−71

Source: Tam, Tam and Zeng (2009, p.179).

Rainwater tanks can also create a number of 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 2010; Mitchell and Rahman 2007, p.41). These benefits are closely linked with other externalities including, ecosystems, nutrients, production, and amenity. Through the capture of stormwater, the nutrient loads to oceans and waterways may be significantly reduced, with estimates for the reduction of phosphorus loads by 68% (Hallmann, Grant and Alsop 2003).

The deferral of the construction of large-scale water supply infrastructure constitutes a significant benefit to the community, both economically and socially. The social benefits occur because alternative large scale infrastructure are often characterised by contention and often result in a certain section of the community ending up in a compromised position. For example, the displacement of landowners may be caused by the establishment of new dams. The infrastructure requirements that can potentially be deferred include new dams, pipelines, and stormwater storage (Coombes and Kuczera 2003, p.1; Blue Scope Steel 2010; Mitchell and Rahman 2007, p.41). The extent of these deferrals will vary greatly depending on the local conditions (Marsden Jacob Associates 2007b, p.13). The reduction in water consumption and stormwater discharge for the Lower Hunter and Central Coast region are described in Table 28.

Table 28: Impact of rainwater use on household demand and stormwater discharge for the Lower Hunter and Central Coast regions, New South Wales.

Impact of rainwater use on household water demand and stormwater discharge for the Lower Hunter region

Zone	Reduction (%)			Average rainfall (mm/yr)	Daily maximum temperature (°C)		
	Mains water use	Stormwater discharge	Peak daily mains water use		Minimum	Average	Maximum
Inner SE Newcastle	50.3	52.1	25.6	932	9	21	42
Hamilton Mayfield	54.3	43.1	27.3	932	9	21	42
Lambton Jesmond	54.6	38.6	35.8	932	9	21	42
NW Wallsend	44.7	55.4	18.3	932	9	21	42
Lake Macquarie East	50.4	50.8	22.2	1013	9	21	42
Lake Macquarie West	50.0	46.6	16.8	1182	9	21	42
Maitland	40.9	52.9	17.2	901	9	24	48
Cessnock	40.3	59.0	24.2	754	9	24	48
Port Stephens	49.1	45.1	12.9	1257	9	23	45

Impact of rainwater use on household water demand and stormwater discharge for the Central Coast region

Zone	Reduction (%)			Average rainfall (mm/yr)	Daily maximum temperature (°C)		
	Mains water use	Stormwater discharge	Peak daily mains water use		Minimum	Average	Maximum
Gosford	48.0	35.0	16.8	1339	10	23	44
Wyong	48.0	41.0	14.1	1212	9	24	46

Source: Coombes et al. (2002, p.311).

Increased use of rainwater tanks can also result in less frequent overloading of sewer systems and overflows, having 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 21) (Vaes and Berlamont 1999).Thus, rainwater tanks can postpone further expansion of sewer systems and provides a comparatively cheap abatement tool for addressing overflow emissions (Vaes and Berlamont 1999). The extent to which these reductions occur is dependent upon seasonal variation and the storage space available in the tanks (Vaes and Berlamont 1999).

In addition to the financial benefits, householders and communities receive benefits relating to recreation and amenity. Gardening is a popular pastime for many and the onset of restrictions significantly impacted on 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 (Marsden Jacob Associates 2007b, p.4; Tam, Tam and Zeng 2009, p.179).

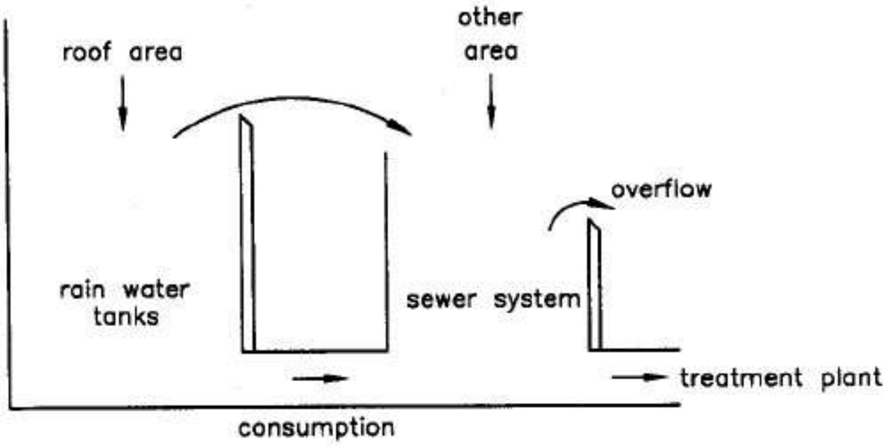


Figure 21: Schematic representation of the used reservoir model to assess the impact of rain water tanks on the overflow emissions.

Source:Vaes and Berlamont (1999, p.57).

Water tanks can also assist in creating water and food security within our communities. 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, Tam and Zeng 2009, p.179; Helmreich and Horn 2009, p.121). Decentralised water supplies create:

- safety nets against terrorist attacks (Mitchell and Rahman 2007, p.41); and
- enable people to continue with small scale productive activities (eg, brewing, food production, household construction) (Helmreich and Horn 2009, p.121; Kahinda, Taigbenu and Boroto 2007, p.1051).

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 2007b, p.5). 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 2007b, p.4).

B. Manufacture and Storage Impacts

The key externalities regarding the manufacture and construction of rainwater storage tanks are the environmental and economic costs, land availability and the health risks associated with the on site storage of rainwater. The most common tank designs involve the use of plastic, steel, or concrete. The externalities associated with the manufacture of these materials are described below (Blue Scope Steel 2010).

1. Plastic: Plastic tanks are becoming increasingly popular, with plastic now being the most common materials used for tanks. Plastic tanks are made from high density polyethylene (HDPE), a derivative of fossil fuels, and have a life-span of approximately 25 years (Blue Scope Steel 2010). In the manufacturing of HDPE tanks, 100% virgin plastic is used due to concerns surrounding UV light exposure. The production of the HDPE for use in the tanks is the largest embodied energy component of the manufacturing process as it requires the significant input of fossil fuels. The manufacturing of HDPE leads to significant CO^2 emissions, as shown in Figure 22.

2. Steel: Rainwater tanks are often manufactured from steel (eg, AQUAPLATE® steel is assumed for this report). These tanks commonly feature corrugated galvanised steel lined with a food grade polymer. The steel tanks last for up to 20 years and at the end of their useful lives may be recycled for scrap. The largest embodied energy component of these rainwater tanks is the steel production, although significant emissions and water saving may occur should the tanks be recycled.

3. Concrete: The materials used in the manufacture of concrete rainwater tanks include steel reinforcement, sand, gravel, water and cement. This model of tank has the lowest life span, lasting only 15 years on average. At the end of the tank's life, it is disposed of through crushing and the steel is able to be reused as scrap.

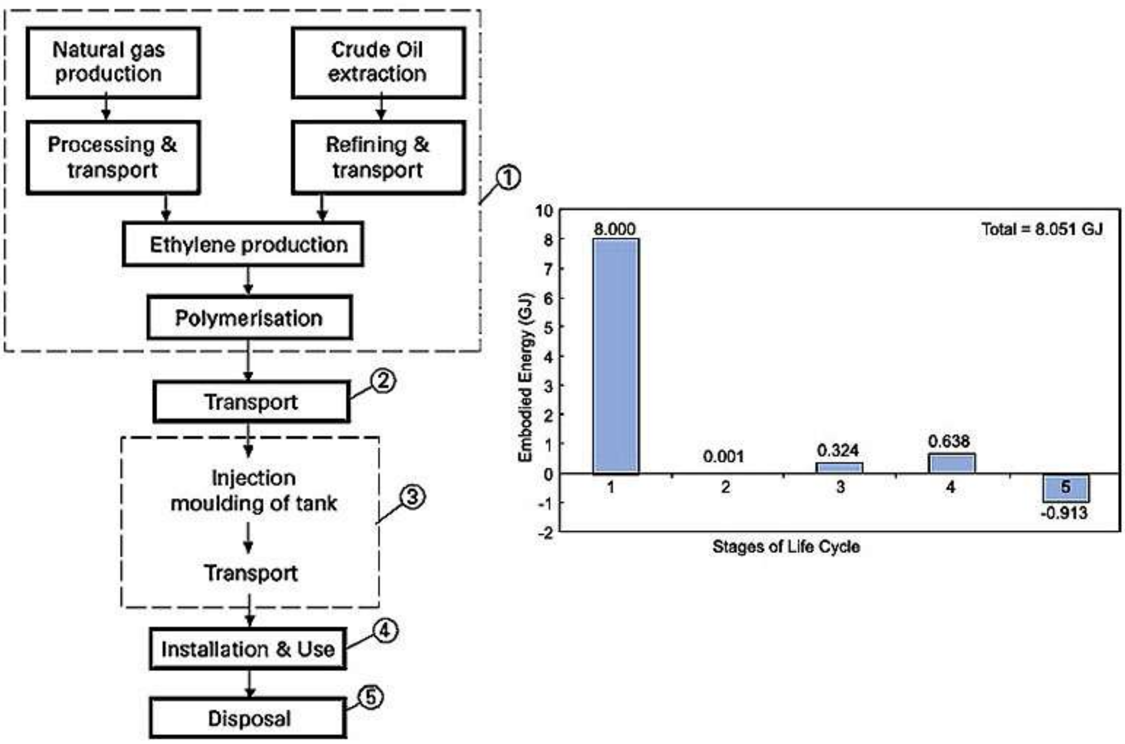


Figure 22: Life cycle tree and environmental burden of 5,000 litres HDPE water tank over its operational life.

Source: Blue Scope Steel (2010, web page).

The largest environmental impact associated with the manufacturing of concrete tanks is the high usage and emissions of energy, water, fossil fuels, SOx and NOx. Around 70% of the impacts of tanks are found to be stemming from the manufacture of the steel reinforcement (Blue Scope Steel 2010). Since the steel may be recycled at the end life of the tank there may be significant energy and water saving at this point (Blue Scope Steel 2010). Surprisingly, there can be up to 50% more steel used in the manufacture of concrete tanks than in (AQUAPLATE®) steel tanks.

Compared to both concrete and HDPE tanks, steel tanks exhibit the lowest environmental embodied energy, fossil fuel, and SOx emissions (Blue Scope Steel 2010). However, in terms of water inputs and NOx emissions, the steel and plastic tanks are fairly similar, both outperforming concrete tanks. The annual GHG emissions from a steel tank are the same as using one 100W light bulb non-stop for approximately seven days.

The cost of rainwater tanks include the tank, installation and pump (see Table 29), as well as land area. 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.

Table 29: Total cost of installing rainwater tanks (by city).

City	Cost of rainwater tank ($)			Pump cost ($)	Plumbing cost ($)	Installation cost ($)	Total cost of installing rainwater tank for outdoor use only ($) (no pump required)			Total cost of installing rainwater tank for outdoor and indoor use ($)		
	2 kl	5 kl	10 kl				2 kl	5 kl	10 kl	2 kl	5 kl	10 kl
Gold Coast	995	1150	2253	355	730	550	2275	2430	3533	2630	2785	3888
Brisbane	890	1350	2060				2170	2630	3340	2525	2985	3695
Melbourne	890	1350	1925				2170	2630	3025	2525	2985	3560
Sydney	810	1190	1925				2090	2470	3205	2445	2825	3560
Adelaide	829	1389	1925				2109	2669	3205	2464	3024	3560
Perth	829	1389	1925				2109	2669	3205	2464	3024	3557
Canberra	810	1190	1925				2090	2470	3205	2445	2825	3557

Source: Tam, Tam and Zeng (2009, p.182)

There is a number of potential health risks associated with the storage of large volumes of water on individual blocks. One of the most hazardous aspects of rainwater tanks is that they may pose a drowning risk (Byard 2008). The case of the drowning deaths of twin two-year old children demonstrates the validity and urgency of this issue (Byard 2008, p.533). The risks of this may be minimised through the removal of all ladders, vegetation, and trellises which may provide points of access. In addition, extra precautions of secure child-proof access points should 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, Montgomery and Walsh 2001, p.13). Mosquitoes are vectors for serious diseases such as dengue fever, Ross River virus and malaria (Ritchie, Montgomery and Walsh 2002, p.13). However, proper maintenance of rainwater tanks to ensure that they have adequate screens, cracks have not formed, and they are drained periodically or treated can minimise the potential for mosquito breeding (Ritchie, Montgomery and Walsh 2002, p.13).

C. Use and Distribution Impacts

A series of externalities arise in regard to the use and distribution of tank water. These mostly concern health and energy consumption. These concerns, raised in the academic literature, are however not necessarily reflections of public perception. A recent study has found that 95% of participants were happy to use the rain water collected for toilet flushing, hot water systems, clothes washing and cooking; whilst 70% saw rainwater tank water as a possible source for 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, Coombes and Dunstan 2006, p.37). Contamination can be a result of: atmospheric deposition; chemicals and micro-organisms; faeces from birds and small mammals (eg, possums); and decaying organic debris (Evans, Coombes and Dunstan 2006, p.37; Helmreich and Horn 2009, p.121). There is potential for public health issues, considering one in five rainwater tank owners (in newly constructed homes) have reported frequent use of the rainwater for drinking and cooking (Gardiner 2009, p.152). The health impacts of rainwater tanks primarily arise due to either contamination of the rainwater or the provision of insect vector breeding grounds (Kahinda, Taigbenu and Boroto 2007, p.1052; Goodall 2000, p.126).

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, Coombes and Dunstan 2006, p.37). 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, p.5432). From 1978 – 2006, there were only six reported cases. However, in a short period since 2006, three new outbreaks have occurred (Lye 2009, p.5432). There may be many other cases of other outbreaks going unreported (Lye, 2009). A list of pathogens commonly found in rainwater supplies in developed countries, their transmission route and the potential risk is described in Table 30.

Table 30: 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 pneumophila	Legionnaires Pontiac fever	Inhalation Inhalation	10,000 Zero
Mycobacterium avium complex	Respiratory Gastroenteritis	Inhalation Oral	Only in immuno-compromised
Salmonella spp.	Gastroenteritis	Oral	41
Cryptosporidium spp.	Gastroenteritis	Oral	22
Giardia spp.	Gastroenteritis	Oral	1

Source: Lye (2009, p.5433).

Specific atmospheric pollutants found in rainwater tanks are dependent upon numerous factors, including quality of the atmosphere of the region (eg, 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).

In addition to airborne contaminants, the catchment surfaces themselves can be a source of heavy metals and organic substances (Helmreich and Horn 2009, p.121). The significance of this impact is dependent on the type of roofing materials used (Helmreich and Horn 2009). 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, p.121; Lye 2009, p.5430).

Long-term exposure to some of the substances that may be present in some rainwater tank water may lead to biological disorders (Lye 2009, p.5430). The health risks are particularly significant when chemical contaminants such as pesticides, herbicides, biocides, organhalogens, and petroleum hydrocarcons are present (Lye 2009, p.5430). However, there is still little in the way of literature dealing specifically with these health concerns (Lye 2009, p.5430). Table 31 outlines the results of recent relevant studies dealing with the health risks associated with rainwater tank water use.

Table 31: Recently identified health risks from rainwater tank use.

Region of Study	Year	Author	Cited in	Description of Study and Results
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	Albrechtsen	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."
Auckland, NZ	2008	Simmons *et al.*	Lye 2009, p.5432	"An outbreak of Legionnaires Disease was reported in an isolated suburb of Auckland, NZ (Simmons *et al.* 2008). Using molecular-based technology, they showed that isolates of *L. 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."
South Australia	2006	Heyworth *et al.*	Lye 2009, p.5433	"Epidemiological studies similar to those reported by Heyworth *et al.* (2006) are needed to determine the greatest risk factors for illness directly related to consumption of rainwater. The report suggests that consumption of rainwater by young children from rooftop collection systems in South Australia did not increase the risk of gastroenteritis relative to piped water sources."
Mount Barker, Western Australia	2006	Tam *et al.*	Tam, Tam and Zeng 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. Thermotolerant coliforms were detected in three tanks and *E. coli* in two tanks. None of the rainwater tanks sampled tested positive for *Cryptosporidium, Giardia, Campylobacter* or *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."
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 16 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 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."
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 greywater 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."
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."

In terms of addressing the health concerns surrounding rainwater tank use, there is a series of management options which can be used to lower health risks (Sazakli, Alexopoulous and Leotsinidis 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, Alexopoulous and Leotsinidis 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 (Villarreal 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 micro-biological quality (Helmreich and Horn 2009, p.121; Kahinda, Taigbenu and Boroto 2007, p.1051). 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, p.5432). However, some studies 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, Coombes and Dunstan 2006; Kahinda, Taigbenu and Boroto 2007). Figure 23 shows the ways that rainwater may be contaminated by chemicals and biological organisms as well as some of the measures that are in place to prevent contamination.

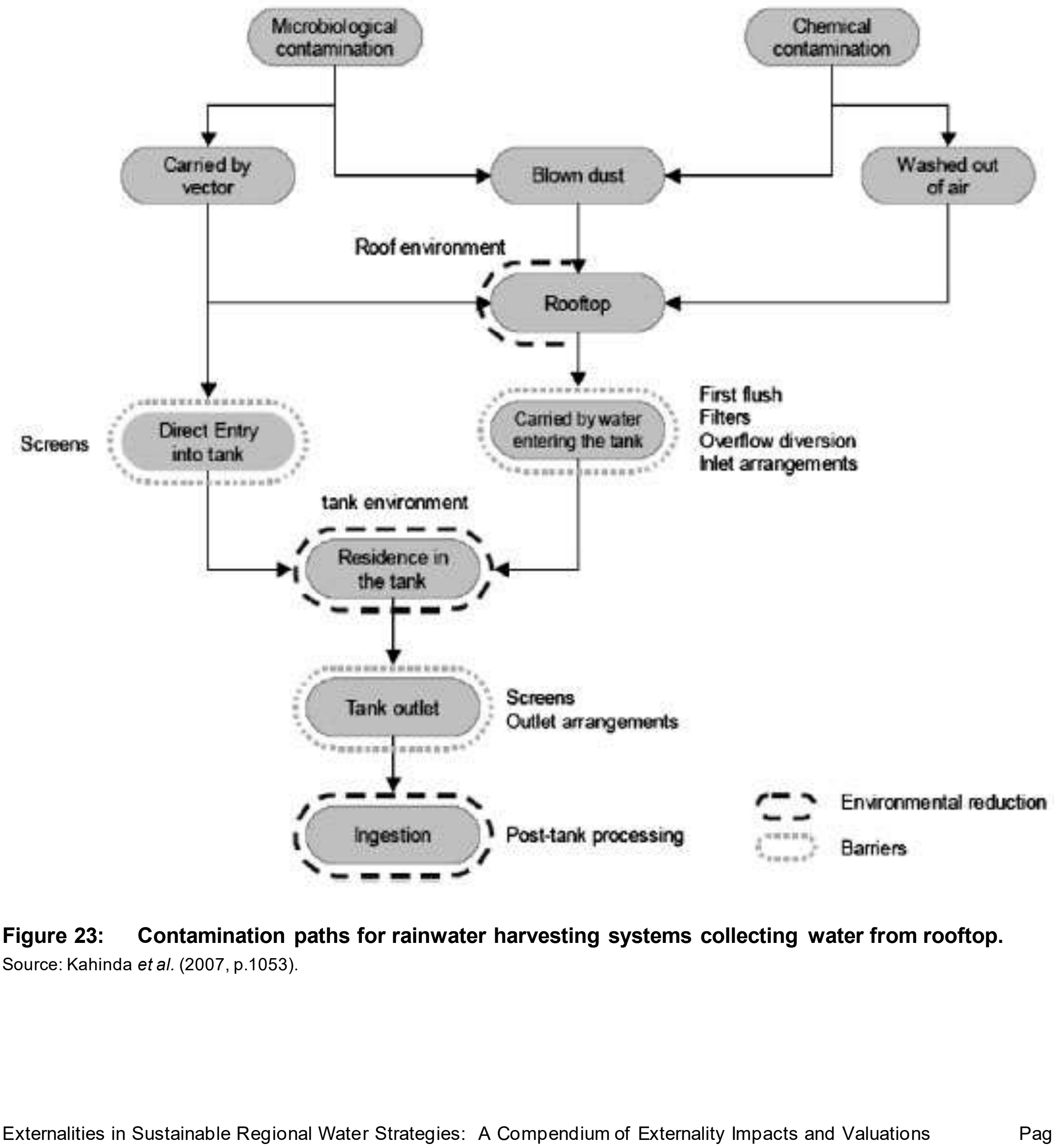


Figure 23: Contamination paths for rainwater harvesting systems collecting water from rooftop.
Source: Kahinda *et al.* (2007, p.1053).

Other studies show rainwater tank water to exhibit little instances of chemical contamination (Lye 2009, p.5431). This variation in scientific opinion leads to the conclusion that there is a lack of clear scientific consensus on this health risk (Evans, Coombes and Dunstan 2006, p.37; Kahinda, Taigbenu and Boroto 2007, p.1052; Kahinda, Taigbenu and Boroto 2007, p.1052). The great levels of variation may be a result of the dependence upon the catchment characteristics, proximity to pollution sources, weather and the regional topography.

In addition to the social externalities associated with the use of rainwater for drinking purposes, the distribution of rainwater for other uses, including irrigation and indoor uses such as flushing toilets, incurs environmental externalities. Despite their recent portrayal as a 'green' water supply option, they are relatively energy intensive. The average energy intensity of a rainwater tank, utilising a commonly used pump and rain switch system, is 1.5 kWh/kL compared with mains supply which is around 1 kWh/kL (Retamal *et al.* 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, tanks are still significantly lower in 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 vary greatly depending on the pump type and size, end-uses and the location and layout of the tank system (Retamal *et al.* 2009, p.viii).

The layout of the rainwater tank storage plays a key role in the energy consumption of the overall rainwater system with the placement of the storage relative to the water's end use affecting the energy required in distribution (Retamal *et al.* 2009, p.22). If the rainwater tank is situated below the end use point, then there will be significant energy use associated with the life required to pump the water up to its desired location. Hence, storage should be placed as high as possible to allow gravitational energy to be used to assist in water delivery.

The most common type of pump used in household water tanks is a fixed speed pump (Retamal *et al.* 2009, p.23). Fixed speed pumps utilise equivalent amounts of power regardless of the volume of water being distributed. This is considered inefficient. An optimal setup would closely match the pump to the rainwater system and to all end uses of the system (Retamal *et al.* 2009, p.24). The energy efficiency of rainwater tanks is variable. For example, based on theoretical modelling, the main energy usage range is predicted to be between 0.8 kWh/kL for a 500 watt fixed speed pump, increasing to 1.6 kWh/kL for a 750 watt fixed speed pump (Retamal *et al.* 2009, p.60). Another factor significantly affecting the energy usage of rainwater tanks is the end use. Sites which use the tank water for toilet flushing, outdoor uses and laundry record average energy consumption of 0.9–2.3 kWh/kL. Whereas, where the tank is used for all household water requirements, the energy use is between 1.4–3.4 kWh/kL. These energy consumption figures are quite high when compared to other water supply options. However, there are numerous ways in which tanks can be made more energy efficient.

Energy efficiency in tanks can be improved through a series of maintenance and technical adjustments. The most common source of inefficiency in tanks is having flow rates from end uses which do not match the energy output of fixed pump systems. Figure 24 shows the energy losses associated with rainwater system inefficiencies. Ensuring that the pump which is selected has an energy input which matches the end use flow requirements will significantly reduce energy use (Retamal *et al.* 2009, p.60). The adoption of energy efficient switching systems and pressure vessels can also assist in lowering rainwater tank's energy usage. Another source of energy wastage is in leaks in the plumbing associated with the rainwater tank. Ensuring leaks are fixed as soon as possible ensures minimal water and energy losses.

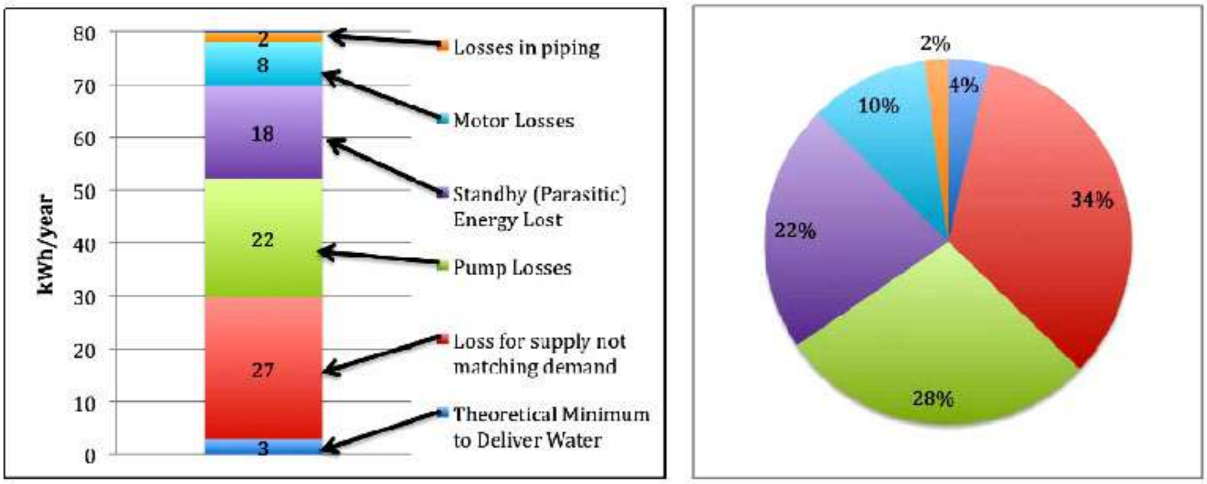


Figure 24: Summary of pump efficiency and losses in a rainwater system.
Source: Retamal *et al.* (2009, p.58).

D. Decommissioning Impacts

Unfortunately, there is a pronounced lack of information on the topic of rainwater tank disposal. Presumably, the impacts would differ with regards to the materials with which the tank was made. Recyclability of the component parts would be another important factor for consideration. It would be valuable to know where most tanks finish up at the end of their lifetime, ie, do owners actually recycle parts, or does the entire tank end up at landfill?

3.7.3 The Externality Tables for Rainwater Ranks

The complete listing and short descriptions of major characteristics, of the externalities identified for rainwater tanks are presented in the tables below.

The information is provided in two table formats. The first table (Table 32) is intended as a summary table and is a condensed version showing some key features in symbolic form (see the table key and paragraph below) and the reference source codes. The second version (Table 33) comprises the extended version with some detail about the nature of the externalities as examined in existing research.

Table 32: Main externalities associated with rainwater tanks - Summary table.

Note: positive (+) or negative externality (-); whether impacts tend to occur predominantly downstream (↓), upstream (↑), or within the immediate surrounds of the supply infrastructure (◙). Reference label numbers are provided at the end of each externality listed. The full reference details are provided in Appendix A.

RAINWATER TANKS												
LIFE CYCLE OR OPERATIONAL PHASE	**EXTERNALITY TYPE (showing if positive or negative effect, main location and reference source number)** (see Appendix A for reference source code details)											
	Greenhouse Gas Emissions	**Energy**	**Water Quality**	**Nutrients**	**Production**	**Recreation**	**Amenity**	**Health**	**Ecosystem**	**Biodiversity**	**Non-use Values[1]**	**Other**
General	**(-)** 224	**(-)** 224, 206		**(+, -, ↓)** 223, 205	**(+, ↓)** 201, 223	**(+, ◙)** 223, 80	**(+, ◙)** 223	**(+,↑,↓,◙)** 75, 83, 173, 266	**(+,↓)** 224, 205		**(+, ◙)** 223	**(+, ◙)** 78, 266, 80, 207, 84
Manufacture	**(-, ◙)** 224, 205	**(-, ◙)** 224, 205	**(+, -,↓,◙)** 86, 205, 80, 82		**(+ ↓)** 86, 205			**(-, ◙)** 80, 82, 224	**(-, ◙)** 224			**(-)** 224
Storage					**(+, ↓,◙)** 86			**(-, ◙)** 53, 224, 99				**(+, ↓,◙)** 86
Distribution		**(-)** 39										
Use (household)	**(-)** 224	**(-)** 224	**(-, ◙)** 80, 82		**(+, ◙)** 205, 209	**(+, ◙)** 83, 80	**(+,-, ◙)** 83, 80, 224	**(-, ◙)** 80, 82, 93, 171, 204				**(+, ◙)** 266
Disposal								**(-, ◙)** 224	**(-, ◙)** 224			

1. Non-use values include option, bequest, intrinsic, vicarious and existence values in the total economic value (TEV) scheme.

Table 33: Main externalities associated with rainwater tanks – Existing study details.

Note: positive (+) or negative externality (-); whether impacts tend to occur predominantly downstream (↓), upstream (↑), or within the immediate surrounds of the supply infrastructure (◙).
Reference label numbers are provided at the end of each externality listed. The full reference details are provided in Appendix A.

<table>
<tr><th colspan="2">RAINWATER TANKS</th></tr>
<tr><th>LIFE CYCLE OR OPERATIONAL PHASE</th><th>EXTERNALITY TYPE, DESCRIPTION (showing if positive or negative effect, main location and reference source number)
(see Appendix A for reference source code details) (see inset table to left for externality type codes)</th></tr>
<tr><td>General
<table>
<tr><th></th><th>Externality Type Codes =></th></tr>
<tr><td>GHG</td><td>Greenhouse gas emissions</td></tr>
<tr><td>En</td><td>Energy</td></tr>
<tr><td>WQ</td><td>Water Quality</td></tr>
<tr><td>N</td><td>Nutrients</td></tr>
<tr><td>P</td><td>Production values</td></tr>
<tr><td>R</td><td>Recreation values</td></tr>
<tr><td>A</td><td>Amenity values</td></tr>
<tr><td>H</td><td>Health values</td></tr>
<tr><td>E</td><td>Ecosystem values</td></tr>
<tr><td>B</td><td>Biodiversity values</td></tr>
<tr><td>NU</td><td>Non-use values</td></tr>
<tr><td>O</td><td>Other</td></tr>
</table></td>
<td>GHG: GHG contributions are 18% higher than that of reticulated water supply (600L tank) (-) 224 (= reference number – see bibliography for details)
En: Comparatively higher cumulative energy demand (67% higher than reticulated water for a 600L tank) (-) 224
En: typical 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. (-) 206
N: Reduction in nutrients in the system, with greatest impacts when water drains to environmentally sensitive areas (+, ↓) 223, 205
P: Extends lifetime of existing large-scale water infrastructure by reducing peak loads and reduction in the cost of water and stormwater infrastructure (+, ↓) 201, 223
R: mitigating the effects of water restrictions on their lifestyle and enabling people to continue to grow food under water restrictions (+, ◙) 223, 80
A: Improving amenity and property values and improving the taste of water in areas of poor water quality (+, ◙) 223
H: Drowning hazard (-, ◙) 75 H: Safety net against terrorist attacks (+, ↑, ↓, ◙) 83
H: Increased use of rainwater tanks may heighten the risk of waterborne disease outbreaks unless appropriate preventative measures are undertaken. (-, ◙) 173, 266
E: Significant reductions in water use, up to 50% (+) 224, 205
E: Substantial reductions in nutrient loads to oceans and waterways (reduces phosphorus loads by 68% over reticulated water for a 600L tank) (+,↓) 224
E: Significant reductions in NO_x flowing to stormwater systems (+,↓) 224 NU: sense of community-mindedness (+, ◙) 223
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 (-) 78
O: Useful measure for water demand in emergency cases (+, ◙) 266
O: could reduce water and food crisis in some regions – increasing water security, especially important in the event of extreme climatic change (+, ◙) 80, 207, 84</td></tr>
<tr><td>Manufacture</td><td>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. (-, ◙) 224, 205
GHG and En: energy and material impacts of water tanks much higher than water from reticulated water supply (-) (especially when pump is used) (-) 224
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 (-) 205
WQ and P: Reduces combined sewer system overflow and peak stormwater flow pressure (+ ↓) 86, 205
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 (-, ◙) 80, 82
H: Carcinogens released throughout manufacture (16% higher than reticulated water for 600L tank) (-, ◙) 224
H and E: Higher release of heavy metals through manufacture and disposal (40% higher than for reticulated water) (-, ◙) 224
H and E: High levels of photo oxidant chemicals stemming from plastic manufacture (4133% higher than reticulated water for a 600L tank) (-, ◙) 224
O: Avoided water storage infrastructure is significant, however, not large enough to offset the impacts of water tank construction and operation (-, ◙) 224</td></tr>
<tr><td>Storage</td><td>P and O: Reductions in Combined sewer overflow (+, ↓, ◙) 86
H: Provision of mosquito breeding sites though risk is very low if tanks are well maintained (-, ◙) 53, 224, 99</td></tr>
<tr><td>Distribution</td><td>En: Consume energy associated with pumping for internal use though short distance tends to make more efficient than other sources (-) 39</td></tr>
<tr><td>Use (household)</td><td>GHG and En: Pumps are often oversized and inefficient (-) 224
WQ and H: Contamination from atmospheric pollutants including particles, microorganisms, heavy metals and organic substances (-, ◙) 80, 82
P: Reduces residential fresh water demands by up to 50% (+, ◙) 205
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 (+, ◙) 209
R and A: Enables watering of gardens under water restrictions (+, ◙) 83, 80
A: Water tanks may impact negatively upon aesthetics of garden space, taking up, on average, $4m^2$ of garden space (-, ◙) 224
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. (-, ↓, ◙) 93, 171, 80, 204
O: rainwater use can work as a kind of environmental education to make citizens aware of sustainable urban water use (+, ◙) 266</td></tr>
<tr><td>Disposal</td><td>H and E: Higher release of heavy metals through manufacture and disposal (40% higher than for reticulated water) (-, ◙) 224
E: Comparatively higher 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) (-, ◙) 224</td></tr>
</table>

4. EXISTING VALUATION ESTIMATES FOR SPECIFIC WATER EXTERNALITIES

Policy and decision makers often need to compare the costs and benefits of water service options across the entire life cycle. If a comprehensive assessment based on long-term and community impacts is sought, then a consideration of externalities becomes vital. One approach for the comparison of options is social cost-benefit analysis, where direct financial costs and benefits are augmented with monetary value estimates of associated externalities. When these full social costs and benefits are distributed across the lifespan of the option considered, total present values are obtained. This then allows for the net benefits of alternatives to be compared. Hence, one way of ensuring that externalities are fully accounted for is to place a monetary value on them (for example, one tonne of greenhouse gas emissions (GHGs) may be estimated as having a full social cost of $25). In this way, externalities can be compared along with direct market costs and benefits. Even where other methods of comparison and decision making are used and do not require monetary valuation (such as multi-criteria analysis), monetary valuations often hold significant sway in the policy process where budgets are constrained.

Providing estimates of the monetary value of externalities presents decision makers and practitioners with an approximation of the societal value of an impact (Chernick and Caverhill 1991). This allows for the incorporation of social, non-market economic and ecological values (of the identified externalities) into the economic assessment of potential policy options. The consideration of externalities alongside priced costs and benefits is essential to ensuring that the total economic value (TEV) of water servicing option impacts is incorporated into policy that is concerned with sustainability and long-term, total community welfare outcomes (see Section 2).

The basic step in monetarising an environmental impact involves biophysical quantification and the assignment of monetary values to the biophysical and related economic and social measures (Matthews and Lave 2000). When there are no existing markets, economists identify surrogate markets or construct hypothetical markets by asking people what they would be willing to pay (WTP) or accept to prevent or be compensated for environmental service loss. However there are many criticisms surrounding the validity and accuracy behind the figures provided from such research (Matthews and Lave 2000).

Many of the externalities which have been identified throughout the preceding sections of this report do not have direct market manifestations; though there are emerging markets for certain externality types (such as greenhouse gases and nutrients). The primary reason for the economic valuation of externalities is to allow comparison across all outcomes which may affect decisions and policy making. Due to the lack of widely-adopted market prices, economic valuation techniques are often employed to establish prices where they are do not currently exist. There are numerous ways through which this can be done, each method featuring its own strengths and weaknesses. A table outlining some key aspects of the major techniques currently in practice can be found in Section 2 of this compendium (see Table 2). The underlying assumption behind many of these valuation methods is that social values should be based on the valuation provided by individual people, independently of whether the individual is an expert in the field (Nunes and van den Bergh 2001). This is seen to be broadly in line with democratic principles.

However, economic valuation is not a *panacea.* There are cases where it should not be carried out at all, such as where there are irreversible impacts which are likely to be undervalued by a society and where it should not be undertaken and interpreted as a comprehensive assessment (Lambert 2003, p.8). This is due to the limitations of valuation processes which are summarised in Section 5.

Table 34 presents an extensive and diverse set of existing economic valuations of externalities relevant to water service options. As noted, the background research has been targeted at a range of options relevant to strategies being considered for SEQ, but the resulting compendium of value estimates will be of widespread use to practitioners concerned with sustainable water management (and, indeed, for strategic resource management purposes in general). The compendium 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). Following Table 34, a brief commentary is provided on each externality category.

A. Greenhouse Gas Emissions

Many of the water service options considered within this compendium emit significant amounts of greenhouse gas emissions (GHGs). Hence, the incorporation of GHG externality valuation is essential in terms of sustainable water management. The climate on Earth is controlled through energy flows from the sun. The energy is mainly provided in the form of visible light. Approximately 70% of the light hitting the Earth is absorbed via the atmosphere to warm the Earth's surface (United Nations Framework Convention on Climate Change 2009). The Earth then sends this energy back into space in the form of infrared radiation. Greenhouse gases alter climate on Earth by preventing infrared radiation from flowing back into space. Whilst GHGs include an array of gases, naturally originating and man-made, this compendium has specifically focussed upon carbon dioxide (CO_2) as it has received the vast majority of research in terms of economic valuation. This narrow scope for GHGs was adopted due to time constraints.

Greenhouse gas emission valuations vary markedly. This wide range has been recognised in other studies and is generally attributed to the scope of impacts considered or reduction targets incorporated, and the complexities and uncertainties within the science of climate change (Hope and Maul 1996, p.211). The prices for CO_2, collected in this study, were found to vary from \$5.94 to \$177.43/tonne CO_2 (\$AUD 2010). This wide range may be a result of differing techniques for calculating the carbon costs, uncertainties surrounding climate change science, or differences in assumed reduction scenarios. When prices are generated via reduction targets, the prices vary depending upon whether the target is a 10% or 30% reduction in emissions by 2020. This occurs because different prices supposedly elicit different levels of altered behaviour, through the differing strength of the incentive to change. The higher prices provide higher incentives to alter behaviour, therefore enabling the achievement of higher reduction targets. For example, a 30% reduction target by 2020 will require significantly higher prices to achieve its target than a 10% reduction target set for the same year.

Another source of variation is due to CO_2 pricing's constant interaction with complex policy targets, technology change, current science, biophysical conditions and market rules (Blyth *et al.* 2009, p.5192). It is increasingly recognised that there is requirement for constant review and alteration of the social cost of CO_2 for assessing societal welfare impacts. Carbon prices should also change as a function of the current concentration of GHG in the atmosphere (Clarkson and Deyes 2002, p.8). Carbon prices are an influential mechanism through which companies are provided with incentives for CO_2 abatement (Blyth *et al.* 2009). This is also true of water management. The inclusion of GHG prices encourages water managers to adopt options which feature mechanisms for CO_2 abatement.

Despite wide variations in the data, there is a clear message which comes from the tables – the cost of reducing climate change pressures is likely to be high. The costs commonly adopted in relevant policy assessment tend to be highly optimistic, and typically far below the upper level of values provided (Chernick and Caverhill 1991, p.48).

There are three generic process for valuing GHGs: damage costing (social costing of carbon); utilising prices operating in existing CO_2 trading markets; and prices stemming from reduction targets specified in policy. Damage costing involves the following stages – quantification of the impacts (incorporating those associated with the adopted perceptions of the risk of global warming); the valuation of the individual impacts; aggregation of the costs associated with the individual impacts; and finally, the translation into a unit cost per tonne (or other specified biophysical unit) (Chernick and Caverhill 1991). GHG costing can also be ascertained through the costs associated with achieving specific levels of reductions as discussed previously.

Table 34: Existing Valuations for Water-Related Externalities – Sorted by Externality Type.

Externality Type	Monetary Value Estimate $AUD 2010 (unless stated)	Location and Year	Total Economic Values (TEV) Covered	Valuation Technique(s) Used
1. Environmental Pressure or State Change Indicators				
GREENHOUSE GAS EMISSIONS (CO_2 only, $/t CO_2)				
Ceronsky et al. (2005)	**28.54 – 42.81**	London, 2002	Indirect Use Values, Option Values and Bequest Values	Damage Cost Modeling of different scenarios
Clarkson and Deyes (2002)	**60.3**	UK, 2002	Indirect Use Values, Option Values and Bequest Values	Global cost of meeting Kyoto targets
River and Sawyer (2008)	**116.39**	Canada, 2008	Indirect Use Values, Option Values and Bequest Values	Policy pricing to target renewable energy investments
Lawson et al. (2008)	**21.92 – 30.35**	Canberra, 2008	Indirect Use Values, Option Values and Bequest Values	CPRS calculated price
Brown and Milne (2010)	**20**	Australia, 2010	Indirect Use Values, Option Values and Bequest Values	Proposed Carbon Price
Hope and Maul (1996)	**70.82 -**	UK, 1996	Indirect Use Values, Option Values and Bequest Values	Global Warming Modeling
Lawson et al. (2008)	**26.25**	Canberra, 2008	Indirect Use Values, Option Values and Bequest Values	Carbon reduction policy target
Diesendorf (2007)	**65.4**	NSW, 2007	Indirect Use Values, Option Values and Bequest Values	Carbon reduction policy target
Australian Government (2008)	**24.15 – 33.6 – 42**	Australia, 2008	Indirect Use Values, Option Values and Bequest Values	Carbon Pollution Reduction Scheme, 2008
Garnaut (2008)	**21 – 42**	Australia, 2008	Indirect Use Values, Option Values and Bequest Values	.Cost of Reaching Carbon Reduction Targets
Point Carbon (2010)	**31.54**	International aggregate data, 2010	Indirect Use Values, Option Values and Bequest Values	Aggregate average of global carbon prices
Existing Permits/ Credit Schemes *Marsden Jacob Associates (2007)*	**40.44**	Australia	Indirect Use Values, Option Values and Bequest Values	Sydney Water (Existing Permits/ Credit Scheme)
GREENHOUSE GAS EMISSIONS (Social Cost of Carbon)				
Social Cost of CO_2 (SCC) *Tol (2004)*	**18.59, 66.38**	Oxford, 2004	Indirect Use Values, Option Values and Bequest Values	Meta-Analysis of damage costs
IPCC Working Group (1996) in Tol (2004)	**10.39 – 227.8**	International modelling data	Indirect Use Values, Option Values and Bequest Values	Damage cost
Pearce (2003 in) Tol (2004)	**5.94 – 29.76 & 7.93 – 53.55**	UK, 2003	Indirect Use Values, Option Values and Bequest Values	Damage cost
Clarkson and Deyes, 2002	**177.43**	UK, 2002	Indirect Use Values, Option Values and Bequest Values	Damage cost
Pratt (2002)	**46.8**		Indirect Use Values, Option Values and Bequest Values	Damage cost
WATER QUALITY				
Water Quality (Usability) *Carson and Mitchell, 1993* *Birol, E., Karousakis, K., and Koundouri, P. (2006)* A) Unusable – Boatable: B) Boatable – Swimming: C) Boatable – Fishable: D) Fishable – Swimmable:	A) **245.6,** B) **363.95,** C) **67.15,** D) **49.54** (/yr/hh)	US, 1993	Direct Use Values	Contingent valuation (CV)
Water Quality (Appearance) *Blamey et al (1999)*	**24.64** (/yr/hh)	Australia, 1999	Indirect Use Values, Option Values, Bequest Values,	CV
Michael et al (1996) in Taylor (2005) A) Sydney B) Residents of the Darling River region	A) **27.6 – 162.84** B) **144.9 –211.14** (/yr/hh/as a tax)	Australia, 1993	Indirect Use Values, Option Values and Bequest Values	CV
Water Quality (Property Premiums) *Washington State Department of Ecology (2003)*	**1 – 20%**	Washington, 2003	Indirect Use Values	Hedonic Pricing
Water Quality (Faecal Coliform Level per m3) Increases of 100 faecal coliform counts per 100mL in receiving waters *Leggett and Bockstael (2000) in Taylor (2005)*	**1.5%** (% reduction in house prices)	Chesapeake Bay, Maryland, 2000	Direct Use Values	Hedonic Pricing
Water Quality (Suspended Solids) WTP for a small reduction, 10mgl−1 of suspended solid concentration in tap water from 335mgl−1 range *Um et al (2002)*	**0.727**	Pusan, Korea, 2002	Direct Use Values	? Presume CV
Water Quality (Bottled Water) Bottled water to avoid organic contamination Abdalla (1994)	**61.09 – 629.51**	Pennsylvania, 1994	Direct Use Values, Option Values	Avertive Expenditure
Water Quality (Suspended Solids) Small reduction, 10mgl−1 of suspended solid concentration in tap water *Um et al (2002) in Birol et al (2006)*	**1.116 – 2.79** (/yr/hh)	Pusan, Korea, 2002	Direct Use Values	CV ?

Externality Type	Monetary Value Estimate $AUD 2010 (unless stated)	Location and Year	Total Economic Values (TEV) Covered	Valuation Technique(s) Used
Water Quality (Thresholds and Standards) WTP for improvements in coastal water quality up to current EU mandatory levels *Georgiou et al. (1998) in Hanley, Bell and Alvarez-Farzio (2003)*	**19.62 – 28.16**	UK, 1998	Direct Use Values	CV Surveys
WTP for improvements to current EU water quality standards in two towns A) Town 1 B) Town 2 *Hanley and Kristrom (2002)*	A) **17.16 – 22.50** B) **9.86 – 12.19**	Scotland, 2002	Direct Use Values	CV Surveys
Water Quality Hypothetical water quality improvements lead 1.3% increases in trip frequency resulting in consumer surplus *Hanley, Bell and Alvarez-Farzio (2003)*	**0.89, 10.81**	UK, 2003	Direct Use Values	CV Surveys and Econometric analysis
Water Quality (Other) *Nunes and ven den Bergh (2001)*	**67.24 – 1269.74**	Meta-Analysis of global literature	Direct Use Values	Meta-Analysis of water-quality data
WTP to avoid interruptions in water service and overflows of wastewater. A) to reduce the frequency of interruptions occurring 1/10 yrs B) to reduce the length of water service interruptions of 1hr C) to reduce frequency of interruptions of 24h. *Yapping (1998)*	**202.87**	China, 1998	Direct Use Values	Travel Cost Method
Reducing Interruptions to Water Services (WTP) A) Reduce the frequency of interruptions when they face one interruption in ten years, B) Face monthly interruptions D) Reduce length of interruptions of 24hr *Hensher et al. (2004) and Birol et al (2006)*	A) **120.13,** B) **58.13,** C) **4.69**	Australia, 2004	Direct Use Values, Option Values	Choice Experiment Method
NUTRIENTS				
NITROGEN (N)- Point source Industry (Soda Factory) *Gaylard (2005)*	**29250 – 146250**	Adelaide, 2005	Direct Use Values, Indirect Use Values and Option Values	MBI Data
Average annual point source load reduction *Alam, Rolfe and Donaghy (2008)*	**861**	Queensland, 2008	Direct Use Values, Indirect Use Values and Option Values	Modeling data
Point Source Nutrient Abatement costs *Environmental Protection Agency (2008)*	**63 000 – 73.5mill**	Brisbane, 2008	Direct Use Values, Indirect Use Values and Option Values	Offset Modeling
NITROGEN (N)- Diffuse Source load reduction and treatment Industry (Soda Factory) *Gaylard (2005)*	**117000 - 936000**	Adelaide, 2005	Direct Use Values, Indirect Use Values and Option Values	MBI Data
Average annual cost of diffuse source load reduction *Alam, Rolfe and Donaghy (2008)*	**8 980.5**	Queensland, 2008	Direct Use Values, Indirect Use Values and Option Values	Modeling data
Diffuse source nutrient abatement costs per year *Environmental Protection Agency (2008)*	**38 850 – 53.6mill**	Brisbane, 2008	Direct Use Values, Indirect Use Values and Option Values	Offset Modeling
NITROGEN (N) - Treatment Costs Industry (Soda Factory) *Gaylard (2005)*	**234 000**	Adelaide, 2005	Direct Use Values, Indirect Use Values and Option Values	MBI Data
NITROGEN (N) - Current Charges *Marsden Jacobs Associates (2007)*	**872** (/kg)	Australia, 2007	Direct Use Values, Indirect Use Values	Market Data
PHOSPHORUS (P) - Point Source Average annual point source load reduction *Alam, Rolfe and Donaghy (2006)*	**1 073** (/t)	Queensland, 2006	Direct Use Values, Indirect Use Values	Modelling data
Point Source Nutrient Abatement costs annual *Environmental Protection Agency (2006)*	**64 050 – 11.6mill**	Brisbane, 2008	Direct Use Values, Indirect Use Values and Option Values	Offset Modeling
PHOSPHORUS (P) - Diffuse Source Average annual cost of diffuse source load reduction *Environmental Protection Agency (2008)*	**41 721.75 -**	Brisbane, 2008	Direct Use Values, Indirect Use Values and Option Values	Offset Modeling
Diffuse source nutrient abatement costs *Environmental Protection Agency (2008)*	**21 000 – 191.1mill**	Brisbane, 2008	Direct Use Values, Indirect Use Values and Option Values	Offset Modeling
Waterway Health WTP for waterway health, stream improvements from: A) 'moderately polluted to unpolluted' B) 'severely polluted' to 'moderately polluted' C) 'severely polluted' to 'unpolluted' *Farber and Griner, 2000 and Taylor (2005)*	**A) $33 - $65** **B) 46 – 143** **C) 96 - 143** (/yr/hh for 5 years)	Pennsylvania, 2000	Indirect Use Values, Option Values, Bequest Values, Vicarious Values	CV

Externality Type	Monetary Value Estimate $AUD 2010 (unless stated)	Location and Year	Total Economic Values (TEV) Covered	Valuation Technique(s) Used
ECOSYSTEM				
Ecosystem **Improvement to Flows** improvement in river flows from no to some rivers and from some to all rivers *Blamey, Gordon and Chapman (1999)*	**57.54, 30.4** (/yr/hh)	ACT, 1999	Direct Use Values, Indirect Use Values, Option Values, Bequest Values, Vicarious Values	Choice Modelling
Ecosystem – Wetlands Decrease in the distance to the nearest wetland increase in property value. *Asano (2001)*	**$582.40/304.8** (/1,000ft closer after initial mile from wetland)	Japan, 2001	Direct Use Values	HP
WTP to protect the Nadgee Nature Reserve (Aust.). *Bennett (1984) in Nunes and van den Bergh (2001)*	**67.12**	Australia, 1984	Use Values, Direct Use Values, Bequest Values, Vicarious Values, Existence Values and Intrinsic Values	CV
WTP to support a single program aimed at enhancing wetlands and habitat *Hoehn and Loomis, 1993 in Nunes and van den Bergh (2001)*	**144.67 – 277.27**	California, 1993	Bequest Values, Vicarious Values, Existence Values and Intrinsic Values	CV Survey
Marginal implicit price of reducing the distance to the nearest wetland A) by 1m B) If more than one wetland within 1.5km of property, second wetland increase property price *Tapsuwan, Ingram and Brennan (2007)*	**A) 504.67,** **B) 6628.29**	Western Australia, 2007	Direct Use Values	Hedonic Pricing
50ha wetland estimate total premium on sales due to wetland proximity *Tapsuwan, Ingram and Brennan (2007)*	**339.8M**	Western Australia, 2001	Direct Use Values	Hedonic Pricing
A) Value of the recharge function for wetlands B) average welfare change for a 1-m change in water levels Acharya and Barbier (2002)	**A) 20468.93 &** **B) 1.84**	Nigeria, 2002	Indirect Use Values	Production Function - Avertive Expenditure
Ecosystem services A) estuaries B) wetlands *Costanza et al, (1997)*	**A) 37149.43 &** **B) 24056.35**	US, 1997	Indirect Use Values	Various
Wetlands Value A) Globally B) Utilisation in Canada: functions in water purification and as pollution sinks C) regulating peak floods. *Costanza et al (1997)*	**A) 7.53815 (trillion),** **B) 31129.04,** **C) 84650.32**	US, 1997	Indirect Use Values	Various
Mean WTP for wetlands *Nijkamp, Vingidni and Nunes (2008)*	**45.56**	Meta-analysis of global literature	Direct Use Values, Indirect Use Values, Option Values, Bequest Values, Vicarious Values	Meta-Analysis of predominantly CV Survey data
Bergkamp, G., McCartney, M., Dugan, P., McNeely, J., and Acreman, M. (2000)	**5.7bill**	Canada, 1981	Direct Use Values, Indirect Use Values, Option Values, Bequest Values, Vicarious Values	
Value of non-use wetland habitat *Nunes and van den Bergh (2001*	**11.17 – 123.6**	Meta-analysis of global literature	Direct Use Values, Indirect Use Values	CV Studies into a Meta-Analysis
Ecosystem - Waterway Health WTP to improve health of creeks and rivers in the area *Thomas et al. (2002)*	**184.73 – 221.29**		Indirect Use Values, Bequest Values, Vicarious Values, Existence Values and Intrinsic Values	CV
WTP as an environmental levy over 20yrs to restore 10km of nearby waterways. *Van Bueren and Bennett (2000)*	**0.107**		Option Values, Bequest Values, Vicarious Values, Existence Values and Intrinsic Values	CV
WTP $0.26 per % of river estuary in good health *Straton and Zanden (2009)*	**$0.3**	Queensland, 2009	Option Values, Bequest Values, Vicarious Values, Existence Values and Intrinsic Values	Choice Modeling
WTP for an increase of 1% in the length of river with healthy vegetation and wetlands *Bennett and Morrison (2001)*	**1.27 – 2.56**	ACT, 2001	Option Values, Bequest Values, Vicarious Values, Existence Values and Intrinsic Values	Choice Modeling
Mean WTP for watercourses *Nijkamp, Vingidni and Nunes (2008)*	**3.018**	Meta-analysis of global literature	?	Meta-Analysis of predominantly CV Survey data
Ecosystem – Beaches/Coastal Areas WTP for the protection of beach ecosystems *Nunes and van den Bergh (2001)*	**15.17 – 24.74**	Meta-analysis of global literature	All?	Meta-Analysis of predominantly CV Survey data
Value of non-use coastal habitat ranges *Nunes and van den Bergh (2001*	**12.6 – 71.2** (/yr/hh)	Meta-analysis of global literature	Bequest Values, Vicarious Values, Existence Values and Intrinsic Values	Meta-Analysis of predominantly CV Survey data
WTP (in relation to coastal ecosystems); A)aesthetic services B) for land cover saltwater wetland, marsh or pond C) near shore island D) beaches *Liu and Stern (2008)*	**A) 4121.88,** **B) 2693.97,** **C) 45.53,** **D) 46.43** (/yr/hh)	Australia, 2008	Option Values, Existence Values	Meta-Analysis of CV studies

Externality Type	Monetary Value Estimate $AUD 2010 (unless stated)	Location and Year	Total Economic Values (TEV) Covered	Valuation Technique(s) Used
Ecosystem – Fisheries WTP per recreational angler in Moreton Bay for the preservation of a fishery threatened by pollution *KPMG (1998)*	**555.60**	Brisbane, 1998	Direct Use Values, Option Values	Travel Cost
Ecosystem – Habitat Value of natural areas providing for habitat/recreation ranges *Nunes and van den Bergh (2001)*	32 123 364	Meta-analysis of global literature	Direct Use, Option Values, Bequest Values, Vicarious Values, Existence Values and Intrinsic Values	Meta-Analysis of predominantly CV Survey data
BIODIVERSITY				
Biodiversity – Fish WTP over 20yrs to increase fish populations by 0.2% to 0.5%. *Layton et al (1999)*	**192.6m**	US, 1999	Option Values, Bequest Values, Vicarious Values, Existence Values and Intrinsic Values	CV
WTP for presence of additional species of native fish in river *Bennett and Morrison (2001)*	**9.85**	NSW, 2001	Option Values, Bequest Values, Vicarious Values, Existence Values and Intrinsic Values	Choice Modelling
Straton and Zanden (2009)	**4.40**	Queensland, 2009	Option Values, Bequest Values, Vicarious Values, Existence Values and Intrinsic Values	Choice Modelling
WTP for an additional fish species *Bennett and Morrison (2001)*	**2.56 – 3.84**	NSW, 2001	Option Values, Bequest Values, Vicarious Values, Existence Values and Intrinsic Values	Choice Modeling
WTP per 1% increase in population of native fish along Murrumbidgee River *Whitten and Bennett (2001)*	**0.42**	Australia, 2001	Option Values, Bequest Values, Vicarious Values, Existence Values and Intrinsic Values	CV
WTP for an additional fish species *Bennett and Morrison (2001)*	**2.56 – 3.84**	NSW, 2001	Option Values, Bequest Values, Vicarious Values, Existence Values and Intrinsic Values	Choice Modeling
WTP or the restoration of the Atlantic salmon into one river in Massachusetts *CSIRO (2007)*	**22.14 – 30.17**	US, 1997	Option Values, Bequest Values, Vicarious Values, Existence Values and Intrinsic Values	CV
Biodiversity – Waterbirds WTP for additional species of waterbird other fauna species *Bennett and Morrison (2001)*	**4.26**	NSW, 2001	Bequest Values, Vicarious Values, Existence Values and Intrinsic Values	Choice Modeling
WTP for 1% increase in native wetland and woodland birds *Whitten and Bennett (2001)*	**0.70**	Australia, 2001	Option Values, Bequest Values, Vicarious Values, Existence Values and Intrinsic Values	CV
Additional for waterbird and other fauna species. *Bennett and Morrison (2001)*	**1.279 – 2.56**			
WTP per 1% increase in native birds or per breeding pair. *Straton and Zanden (2009)*	**6.7**	Queensland, 2009	Option Values, Bequest Values, Vicarious Values, Existence Values and Intrinsic Values	Choice Modeling
WTP for the conservation of waterfowl in wetlands. *Nunes and van den Bergh (2001)*	**80.55 – 96.66**	US, 1993	Option Values, Bequest Values, Vicarious Values, Existence Values and Intrinsic Values	CV
WTP for the conservation of the migratory waterfowl in the Central Flyway (US). *Desvousges et al. (1993)*	**88.2 – 106.14**	US, 1993	Bequest Values, Vicarious Values, Existence Values and Intrinsic Values	CV
WTP to prevent losses in habitat for uncommon species A) 1 species B) 5 species *Blamey, Gordon and Chapman (1999)*	A) **6.85**, B) **32.86**	ACT, 1999	Bequest Values, Vicarious Values, Existence Values and Intrinsic Values	CV
Biodiversity – Endangered Species (unspecified) WTP for an additional endangered species to be preserved in wetlands. *Bennett and Morrison (2001)*	**5.7, 5.87**	NSW, 2001	Option Values, Bequest Values, Vicarious Values, Existence Values and Intrinsic Values	Choice Modeling
WTP to reduce habitat loss per uncommon species. *Gordon, Chapman, Blamey (2001)*	**30.7**	Australia, 2001	Bequest Values, Vicarious Values, Existence Values and Intrinsic Values	CV
WTP for preservation of all endangered species. *Nunes and van den Bergh (2001)*	**167.56**	Meta-analysis of global literature	Bequest Values, Vicarious Values, Existence Values and Intrinsic Values	Meta-Analysis of predominantly CV Survey data
Mean WTP for endangered species protection *Nijkamp, Vingidni and Nunes (2008)*	**204.16**	Meta-analysis of global literature	Bequest Values, Vicarious Values, Existence Values and Intrinsic Values	Meta-Analysis of predominantly CV Survey data
Biodiversity – Single Species *Nunes and van den Bergh (2001)*	**6.98 – 175.98**	Meta-analysis of global literature	Bequest Values, Vicarious Values, Existence Values and Intrinsic Values	Meta-Analysis of predominantly CV Survey data
WTP for the conservation of Leadbeaters Possum Jakobsson and Dragun (1996)	**41.18**	Australia, 1996	Bequest Values, Vicarious Values, Existence Values and Intrinsic Values	CV?
Biodiversity – Genetic Diversity Value of genetic and species diversity *Nunes and van den Bergh (2001)*	**$212.5k – $3.9mill** (/yr in bio-prospecting)	Meta-analysis of global literature	Direct Use Values, option Values	Meta-Analysis
INBio and Merck, pay for the right to study 2000 samples of Costa Rican genetic pool. *Nunes and van den Bergh (2001)*	**1.7mill**	Costa Rica	Direct Use Values, option Values	Bio-Prospecting prices – Market Data

Externality Type	Monetary Value Estimate $AUD 2010 (unless stated)	Location and Year	Total Economic Values (TEV) Covered	Valuation Technique(s) Used
Biodiversity WTP Macquarie Marshes *Morrison et al. (1999)*	**27.28 – 124.92**	Australia, 1999	Non-Use Values	CV
Nijkamp, Vingidni and Nunes (2008)	**48.39**	UK, 2006		
Biodiversity – Wildlife Preservation Mean WTP for wildlife preservation *Nijkamp, Vingidni and Nunes, (2008)*	**3.04**	Meta-analysis of global literature	Option Values, Bequest Values, Vicarious Values, Existence Values and Intrinsic Values	Meta-Analysis of predominantly CV Survey data
Biodiversity – Native Vegetation WTP per % of river or river length covered with healthy native vegetation. *Straton and Zanden, (2009)*	**3.10**	Australia, 2009	Option Values. Bequest Values, Vicarious Values, Existence Values and Intrinsic Values	Choice Modelling
2. Socioeconomic Costs and Benefits				
PRODUCTION				
Production - Commercial Fishing Value of commercial fishing in Moreton Bay *KPMG (1998)*	**4.68mill**	Brisbane, 1998	Direct Use Values	Market Data
Storm water runoff costs US commercial fish and shellfish industry approx. p.a. *US EPA (1997)*	**3.0mill – 61.5mill**	US, 1997	Direct Use Values and Option Values	Market Data
RECREATION				
Recreation - Beaches	**65.68**	Florida, 1990	Direct Use Values and Option Values	Travel Cost
Recreation – Rivers WTP per household per visit for recreation at river sites in northern Victoria. *Walpole (1990)*	**29.38**	Victoria, 1991	Direct Use Values and Option Values	CV
Recreational value of rivers *Sanders et al (1910)*	**73.67, 55.06**	Colorado (1991)	Direct Use Values and Option Values	CV
WTP for recreational opportunities *Siden (1990)*	**39.13**	Victoria (Aust), 1990	Direct Use Values and Option Values	Travel cost
QLD residents spend on recreational fishing *ABS (1993)*	**229.4**	Queensland, 2003	Direct Use Values and Option Values	Market data
Recreation – Fishing Value of freshwater recreation fishing industry A) Brisbane region B) Moreton Bay C) national expenditure in Australia *Taylor (2005)*	**A) 3.7mill, B) 12.0mill, C) 3.6bill**	Brisbane, 2002	Direct Use Values and Option Values	Market Data
WTP water quality increase to be fishable/swimmable. *Straton and Zander (2009)*	**58.15**	Australia, 2009	Direct Use Values and Option Values	Choice modeling
Recreation – Boating Total value of an improvement in water quality to boatable level *Yapping (1998)*	**44.58mill**	China, 1998	Direct Use Values and Option Values	Travel Cost
Recreation – Swimming Total value of an improvement for swimmable quality level. *Yapping (1998)*	**114.17mill**	China 1998	Direct Use Values and Option Values	Travel Cost
WTP per water quality increase to be fishable/swimmable. *Straton and Zander (2009)*	**58.15**	Australia, 2009	Direct Use Values and Option Values	Choice Modeling
Recreation – Other WTP for water quality improvements to enable recreation, WTP as increase to water rates *Green and Tunstall (1991)*	**31.25**	UK, 1991	Direct Use Values and Option Values	CV
AMENITY				
Amenity – Property Premiums – Water Frontage price of a house located within 300m of any body of water raises *US Dept of Housing and Urban Development (1991)*	**28%**	US, 1991	Direct Use Values	Hedonic Pricing
Residential housing with open water frontage *Campbell (2001)*	**80%**	Brisbane, 2001	Direct Use Values	Hedonic Pricing
Properties with frontage onto a constructed wetland in Melbourne attracted a higher price than average block price. *Lloyd (2001)*	**17%**	Melbourne, 2001	Direct Use Values	Hedonic Pricing
homes near restored streams had higher prices than similar homes on unrestored streams. *Streiner and Loomis (1995)*	**3 – 13%**	California, 1996	Direct Use Values	Hedonic Pricing

Externality Type	Monetary Value Estimate $AUD 2010 (unless stated)	Location and Year	Total Economic Values (TEV) Covered	Valuation Technique(s) Used
Amenity – WTP for Waterway Restoration WTP as an environmental levy over 20yrs to restore 10,000ha of land for aesthetic reasons. *Van Bueren and Bennett (2001)*	**1.193**	Australia, 2001	Direct Use Values	Choice Modeling
WTP as an environmental levy over 20yrs to restore 10 000ha of land for aesthetic reasons *Robinson et al. (2002)*	**0.46**	Queensland, 2002	Direct Use Values, Option Values	Citizens Jury and Choice Modeling
NON-USE				
Non-use Values – Rivers WTP for protection of rivers: A) Option Value B) Existence Value C) Bequest Value *Sanders et al. (1990)*	**A) 44.73,** **B) 79,** **C) 103.31**	Colorado, 1990	Option Values, Existence Value, Bequest Values	CV
Values associated with the Rakaia River (NZ): health of in-stream river flows A) Option Price B) Preservation Price *Kerr, Lock and Kennedy (2008)*	**A) 16.26,** **B) 16.05**	NZ, 2008	Option Values, Intrinsic Values, Existence Values	CV
Non-use Values WTP for a 10% reduction in household water use. *Gordon, Chapman and Blamey (2001)*	**12.79**	Australia, 2001	Direct Use Values, Existence Values	CV
Gordon, Chapman and Blamey (2001)	**60.11, - 70.35**	Australia, 1982	Direct Use Values	CV
WTP preserve quality of receiving waters in the US *Greenley et al (1982)* A) Option Value B) Existence Value C) Bequest Value (/yr/hh)	**A) 116.18,** **B) 179.55,** **C) 174.27**		Option Values, Existence Values, Vicarious Values	
HEALTH				
Health Value of a statistical life (VSL) *The World Bank (2003)*	**5.17mill**	US, 2003	Direct Use Values	value of a statistical life (VSL) via wage differential studies in US
VSL in Mexico *The World Bank (2003*	**596 909**	Mexico, 2003	Direct Use Values	Value of a Statistical Life in Mexico
Dixon (1998) WTP for a 0.0001% reduction in the risk of premature death.	**345**	US, 1998	Direct Use Values	CV
Dixon (1998)	**488.52**	US, 1998	Direct Use Values	Cost of illness: for an average emergency room visit (US)
Dixon (1998)	**109.82**	US, 1998	Direct Use Values	Cost of Illness: value of each restricted activity day due to illness (US)
OTHER				
Other WTP to reduce Flooding *Daniel et al, 2009*	−52 to +58% average property price associated with a risk exposure of 0.01 per year.	-	Direct Use Values	CV?

1. See the Appendix A to link codes to the full reference details.

Some of the higher values in the table represent estimations of the broader social costs of carbon. In terms of comprehensive and representative externality valuation, social costs of carbon emissions are likely to be more accurate. Social costs of carbon (SCC) (also known as the “shadow price of carbon”) are a monetary indicator intended to represent the global damage of emitting CO_2 (Guo 2004, p.1). SCC can incorporate damage costs and preventative expenditure related to climate change impacts, such as; displacement, the cost of loss of ocean productivity due to ocean acidification and the cost of loss of agricultural production due to increased drought levels, and the cost of dealing with increasing numbers of natural disasters. Thus the higher the SCC, the greater the justification for the adoption of water service options with less CO_2 emissions. Social costs of carbon are important to include in relevant analyses as they provide estimates which may be closer to more comprehensive externality impacts, thereby incorporating the full costs of CO_2 contribution to global warming.

B. Energy Use

The energy costs presented here are representative of the 'regional reference price' for Qld at the time compiled (16 June 2010). Hence, this price is regionally and temporally specific. The cost presented here is an average across the state from all centralised energy sources (in Qld, this source is primarily based on coal). The cost was sourced from the website of the Australian Energy Market Operator. This site provides data for all Australian states. It is recommended that practitioners consult this site to seek relevant prices at the time a valuation is required (see below).

Australian Energy Market Operator: http://www.aemo.com.au/data/avg_price/averageprice_main.shtml.

C. Water Quality

The water quality valuations covered in this compendium cover a wide range of effects relevant to water servicing option externalities. The values are mostly sourced from willingness-to-pay (WTP) studies. The WTP studies are sourced from around the world, with many of their values for water quality broadly applicable to the SEQ context. There is some overlap between water quality valuations and ecosystem and health values. This occurs because low quality water brings about numerous health concerns, hence often the values and inter-related.

D. Nutrients

Nutrient costing, as a specific form of water quality impact, is limited to nitrogen and phosphorus in this analysis due to time and scope limitations. Nutrient prices are mostly obtained through cost of treatment or load reduction costs. These are further divided into (a) costs derived from the treatment costs associated with specific industries, diffuse source reduction costs, and (b) point source reduction costs. Both nitrogen and phosphorus prices are often a valuation of the damage costs of nitrogen and phosphorus loads to waterways. For example, the cost of treating an algal bloom which is the result of high nutrient levels in the waterway.

Nitrogen exhibits a wide range of valuations with many of the prices being very context-specific and hence of limited potential applicability. Similar observations are applicable to the analysis of the phosphorus valuations covered in the table.

Many publications in the area recommend and detail the creation of nutrient markets. This would involve pricing mechanisms or tradable quotas. Such market schemes would be developed with the aim of reducing nutrient loads to waterways and decreasing treatment costs.

E. Production

There are many forms of production-related externalities linked to water servicing alternatives. For example, desalination may decrease coastal tourism, whereas water recycling may benefit irrigation for agriculture. This diversity leads to difficulty in identifying appropriate valuations for generalised use as they will depend on where an externality is occurring, and will be industry-specific and locationally specific – eg, agriculture in the Lockyer Valley versus fishing in Moreton Bay. Accessing context specific production data should be relatively easy – possible sources include industry annual reports and national economic statistical surveys and publications. Some specific data for fishing are provided in the table but are presented as an example of the types of data which may be relevant to the water options in question.

F. Recreation

Relevant data were only found for water-based recreation values despite the fact that other terrestrial forms are relevant. For example, stormwater harvesting ponds can provide expanded areas of recreation in terms of walking tracks or grounds appropriate for picnicking and other related outdoor pursuits. Again, these valuations will be context-specific and, therefore, caution is required in the application of the table data. For example, people may be less inclined to picnic or walk near a stormwater pond surrounded by scrub than a dam surrounded by rainforest. Typically, the recreational values have been generated through contingent valuation (CV) studies assessing people's WTP for specific recreational activities. The travel cost valuation would also be relevant to recreational values, though no figures were found relevant to this study.

G. Amenity

Amenity is particularly relevant to many of the supply options applicable to SEQ and lack of relevant data suggest that additional valuation studies into aesthetic impacts of water options are needed. Examples include the visual impacts of desalination plants located along coastlines, the aesthetic benefits of stormwater harvesting ponds, and the aesthetic cost of reduced downstream river flows as a result of upstream dams. It is difficult to accurately measure the value of aesthetic externalities as there is no direct market data and the impacts can be hard to quantify.

The valuations provided cover a wide range of topics, though more sources would strengthen the validity of relevant estimates. One area in which a lack of studies was identified was the valuation of coastal values and vegetation/landscape values.

Amenity prices or percentage change in value are commonly assessed by the hedonic pricing method, a revealed preference approach in which preferences are identified through the choices people actually make in day-to-day life. The underlying assumption of the approach is that people are WTP different amounts for different benefit characteristics. Thus, the hedonic pricing methodology uses housing prices to reveal peoples values about a certain characteristic ecosystem or landscape. In this method, prices are compared for houses or land which are similar in all other ways, but with varying proximity to waterway benefits. Differential values are assumed to reflect the consumer's underlying benefits from the waterway features. Often this value is associated with the waterways aesthetics ("water views").

Aesthetic values can also be ascertained directly through eliciting people's WTP for the aesthetic values in question. This approach is less common than the hedonic pricing technique, but is potentially more reliable as a measure of the actual characteristic in question.

H. Health

Water management scenarios can have significant health effects upon individuals and communities (Hackett 2006, p.166). The costing of human life is controversial and difficult for participants – for example asking someone what they would be WTP to avoid the increased chance of 1 in 10,000 of premature death, within a year, is a challenging task (Matthews and Lave 2000, p.1391).

The primary area of demand for this data would be in the estimation of illness and death costs associated with water quality and contamination problems. The risk to individuals will be uncertain as the range of options will have different consequences for individuals, eg, air pollution may impact upon asthmatics more severely than those in good respiratory health (Hackett 2006, p.166). One way of measuring increased health risks is through the increase in likelihood of a person getting ill or dying (Hackett 2006, p.166). Risk assessments are often employed to predict these outcomes (Hackett 2006, p.167). Economists and other researchers create valuations from the results of risk assessments through the *value-of-a-statistical-life* (VSL) approach (Hackett 2006, p.168).

There are a variety of methods through which VSL can estimate the value of illness or death. Most commonly, it will involve information gathered on people's WTP to reduce the probability of premature death. This is likely to be the most applicable to water servicing scenarios. An alternative method is to conduct wage-risk studies in which additional compensation costs for jobs entailing high levels of risks are estimated. This is probably of limited application to water-related scenarios. A third alternative is the use of the cost required to create a regulatory intervention, which is given as a cost per statistical life-year saved through the regulation (Hackett 2006, p.169).

I. Ecosystems

The most common method through which these data were obtained was WTP studies, notably those based upon contingent valuation (CV). A majority of these studies focused upon the value of wetlands and waterway flows. There were relatively few studies specifically valuing ecosystem health in a comprehensive way. There were a number of studies, especially in relation to vegetation, which were equally applicable to ecosystem and biodiversity categories. Other methods through which ecosystem-related values were obtained include replacement and repair costs and hedonic pricing. More data on the replacement and repair values of wetlands would provide important information relevant to this field. Travel cost analysis is another means through which ecosystem values can be established, though no such studies were identified in this review.

Costing ecosystems and their services and functions is a challenging and controversial task (Chernick and Caverhill 1991, p.49). Effective assessment should utilise a multi-disciplinary approach which may prove time-consuming and expensive. Monetary valuation of damage to ecosystems is highly complicated and uncertain (see Figure 25 below). There are also many instances where these data are misused, ie, applied inappropriately (Matthews and Lave 2000, p.1390). Hence, it must be acknowledged that the values presented in the table do not represent a comprehensive set of ecosystem values.

In addition, ecosystem valuations are likely to differ from anthropocentric values, eg, a particular plankton may serve a large variety of ecosystem services and play its part in a complex aquatic food web, but this may not be known and accounted for by those undertaking the valuations (see Figure 25) (Farber, Costanza and Wilson 2002, p.384). Also, valuation often requires the focus upon a very specific attribute of an ecosystem – and it is then hard to distinguish the specific attribute from the ecosystem as a whole. For example, it is problematic to value trees separately from the forests in which they are found (Farber, Costanza and Wilson 2002, p.385).

J. Biodiversity

Many people express discomfort with the valuation of biodiversity, commonly pointing out that the 'intrinsic value' of biodiversity cannot or should not be priced (Nunes and van den Bergh 2001, p.205). This belief encompasses the notion that biodiversity has an independent value of its own, one that is apart from the instrumental value assigned to it by humans (Nunes and van den Bergh 2001, p.205). In opposition to this view, some see placing a monetary value on nature as a logical activity; that is, biodiversity is used for instrumental purposes and that these purposes have values attached (Nunes and van den Bergh 2001, p.205).

A majority of the values in this category were found in studies which had used WTP – most commonly via CV-based studies. A few sources were based on the value of bio-prospecting explorations.

Biodiversity valuation confronts a series of limitations. Firstly, biodiversity valuations often overlap, especially when values occur at different levels (ie, the total value of all birds to a specific region as opposed to the value of a specific bird within that same region), leading to difficulties in aggregation (Nunes and van den Bergh 2001, p.206). Another issue relating to aggregation occurs when a specific species of an affected region are valued, but a number of species are not (ie, is the unvalued frog worth as much as the valued bird?). The third issue is that of accounting for the holism embodied within the concept of biodiversity (Nunes and van den Bergh 2001, p.206). Biodiversity is an abstract notion related to a complex series of systems and interactions, which are difficult to 'de-associate' from one another (Nunes and van den Bergh 2001, p.206). Hence, to assume humans have sufficient knowledge to provide accurate valuations may be flawed (Nunes and van den Bergh 2001, p.206).

K. Non-Use Values

Non-use valuations proved difficult to locate for water supply externalities. Non-use values include option values, bequest values and existence values. For example, if a development was to push a species into extinction, what would someone be willing to pay to preserve the existence of that species for future generations (despite the fact that that particular person may never be able to see that species). The valuations that are provided are those which form the complement of use values in TEV (as described in the Methodology section, Figure 1). Non-use values are important and should be considered in water management decision making. Non-use valuation of water supply externalities is an important field of research for the future.

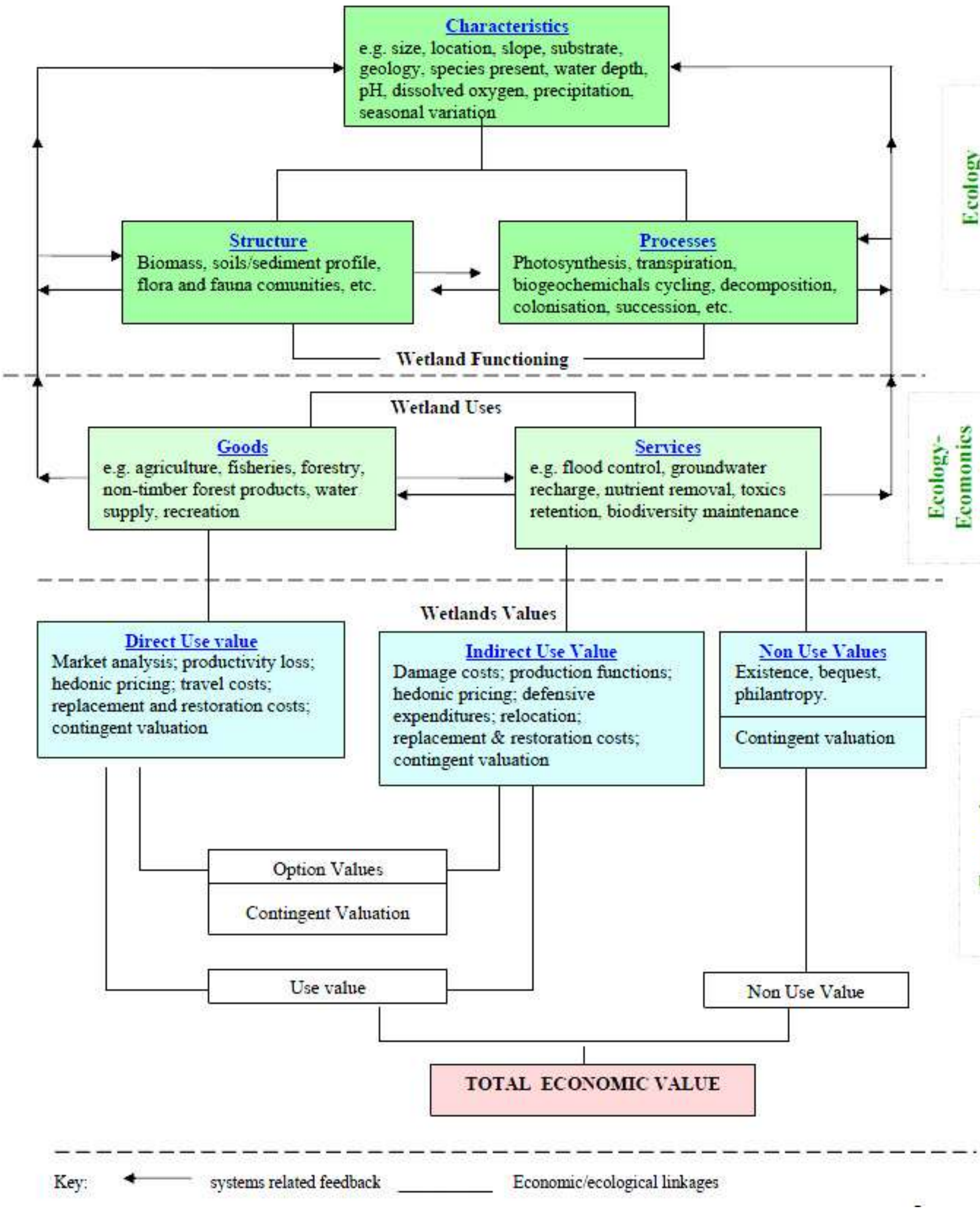


Figure 25: The Complex Connections Associated with Ecosystem Valuation – Wetland Case Study.
Source: Lambert (2003, p.5).

L. Other

The externalities provided in the "Other" category are external effects which did not specifically fit within the other groups. These will be different for individual water servicing options, e.g. they may range from the collection of lint causing clogging in drains (greywater) to the flood mitigation properties of a wetland. Flood mitigation was a recurring theme, with one valuation (in the form of % impact on housing prices) provided.

5. DISCUSSION

The incorporation of externalities into resource management decision-making is an ambitious but potentially very valuable task. The logic of the compendium is to provide an extensive scheme that identifies and, where possible, provides indicative economic valuation estimates of the full range of social costs and benefits associated with a set of common options available for providing secure, reliable and sustainable water resources for a region. Without a consideration of externalities, decisions tend to be made on the basis of a combination of financial analyses and political lobbying, and draw upon partial, and often biased, assessments. Financial analysis includes only direct costs and benefits that are clearly part of the market transactions involved in initiating and operating a project – such as the construction, operation and treatment costs of supplying water from a new dam. Externality analysis provides more systematic and comprehensive inputs to guide decision-making by identifying, quantifying and assessing the relative trade-off values of all costs and benefits over the long term.

Comprehensive externality analyses are consistent with the notion of integrated resource management as the underlying objective is to trace the extensive interconnections and flow-on effects across natural and economic systems (for example, see Beven 2007; Coombes and Kuczera 2003; Fletcher 2008). Ideally, this requires consideration of life cycle and supply chain effects, as well as downstream biophysical, social, and economic implications of proposed water options and technologies.

A critical assumption underlying the proposed use of the compendium is that the benefits of externality analysis are not solely dependent on the ability to convert all costs and benefits into dollar values. Indicative monetary values can be very useful in decision-making if there is explicit treatment and awareness of the range of estimated values, the reliability, completeness, and accuracy of underlying data, and the need for specific contextual information on impacts. As such, economic valuation estimates of "unintended" impacts captured in externality analysis provide potentially valuable inputs *as one part* of the decision-making process for water. Such values provide decision makers and practitioners with an approximation of the societal value of an impact (Chernick and Caverhill 1991, p.46). This allows the social and ecological values of the identified externalities to be incorporated into their processes and policies. The consideration of externalities alongside financial costs and benefits is essential to ensuring that the total economic value (TEV) of water supply impacts are incorporated into sustainable policy processes.

Economic valuations of externalities can be applied in many ways and to vary degrees in strategic water research, management and planning. It is quite rare to see the full-scaled adoption of private and external costs and benefits into economic decision-making frameworks such as cost-effectiveness (CEA) or cost-benefit analysis (CBA). Indeed, this would represent strong faith in the reliability and inclusiveness of market measures and monetarisation. Beyond the expensive nature of fully-fledged CEA or CBA, and some serious conceptual issues limiting the efficacy of single figure outputs, primary research to accurately establish context-specific monetary values can also require extensive time and financial resources.

However, the wider application of general externality identification and valuation techniques for environmental management is gaining support. For example, it has been suggested that:

> *"...externalisation of costs is a major factor leading to the loss of natural ecosystems... Policy-makers need to identify the value of this loss of welfare and implement financial and institutional mechanisms to assimilate these costs into the accounting structure" (Bergkamp et al. 2000, p.v).*

Further support is expressed by Alain Lambert, Senior Advisor to the RAMSAR Convention, who states:

> *"Translating these many values into economic terms is of primary importance if we are to convince of the importance of these ecosystems as life-supporting systems. This is a relatively new science but promising progress is being made." (Lambert 2003, p.4).*

Indeed, there is a common theme in environmental analysis literature of the need for methodologies and information for the identification and tentative valuation of water option-related externalities to enable useful inputs into decision-making and policy formation processes.

As noted, two major outputs of this report are: (1) the systematic identification, compilation and description of major externalities associated with seven major water servicing options; and (2) a survey of existing research and subsequent collation an extensive range of monetary values for these externalities.

A summary of some of the most common and/or significant externalities identified for each option studied is presented in Table 35. As in the detailed tables from which they are extracted (in Sections 3 and 4), the summary table notes whether the individual externalities tend to be benefits (+) or costs (-); whether they occur upstream, downstream or in-situ and the life cycle or operational phase of the option. It also lists the overall major types of externality associated with each option (for example, "nutrients", "greenhouse gas emissions" or "recreation" effects) and comments on notable aspects of the existing valuations for the externalities linked to each option. The seven options are *stormwater harvesting, rainwater tanks, centralised wastewater recycling, dams, desalination, groundwater and greywater reuse*, and the stages typically considered within each option are *construction, collection, treatment, storage, use/distribution and decommissioning*.

Although the table is just a brief summary of the report's detailed research and findings, it demonstrates how the compendium can help water management researchers, planners and policy makers identify key externalities, links to biophysical and socioeconomic impacts, and indicative values per unit of the externality impacts. This information can be applied to decision-making processes to whatever extent they see appropriate. Table 35 is presented as an explanatory aid or a starting point – the detailed data are presented in Sections 3 (externality identification) and Section 4 (externality economic valuation estimates).

Table 35: Summary table of the key externalities associated with each water servicing option considered in the study.

KEY EXTERNALITIES	
STORMWATER HARVESTING	
• Reduction in pollution to waterways from stormwater runoff, leading to downstream ecosystem benefits (Collection and Treatment Stages (+,↓, ◙)) • Decreased nutrient build up in waterways through reductions in stormwater runoff. (Collection and Treatment Stages (+,↓, ◙)) • Provision of recreational spaces (when incorporating wetlands or ponds). (Storage Stages (+,◙)) • Enhanced flood mitigation. (Storage Stages (+,↓, ◙)) • Increases in surrounding property values, stemming from amenity benefits of water bodies. (Storage Stages (+,◙)) • Potential to facilitate health concerns – e.g. mosquito breeding sites and drowning hazards. (Storage Stages (-,◙)) • Fauna and flora benefit through aquatic habitat provision. (Storage Stages (+,◙))	**Main externality types** Nutrients (N), Recreation (R), Ecosystem (E) **Valuation Examples** **($AUD 2010)** • Improvement to Environmental Flows: $57.54 - *Blamey, Gordon and Chapman (1999)* • Mean WTP for Wetlands $45.56 - *Nijkamp, Vingidni and Nunes (2008)* • Value of Habitat/recreation area provision $32.1 mill/yr - *Nunes and van den Bergh (2001)*
RAINWATER TANKS	
• Comparatively higher energy usage than reticulated mains water (mostly due to inefficient pump systems). (All Stages (+, ↑, ↓, ◙)) • Higher greenhouse gas emissions than reticulated water. (All Stages • Enables gardening and home food production to occur despite drought conditions and water restrictions (this leads to amenity and recreational benefits). (Use/Distribution Stages (+,◙)) • Decreased fresh water usage, which may defer the need for additional water infrastructure. (Use Stages (+,↓, ◙)) • Decreased pressure on drainage infrastructure in flood events. (Collection and Storage Stages (+,↓, ◙)) • Potential contamination risk leading to negative health consequences. (Storage and Use Stages (-,◙)) • Possible mosquito breeding site if poorly maintained. (Storage Stages (-,◙)) • Health and environmental problems stem from the pollutants and wastes associated with the manufacture of the tanks. (Manufacturing Stages (-,◙)) • Waste disposal is a source pollution and of potential environmental and health contamination risk. (Disposal Stages (-,↓, ◙))	**Main externality types** Greenhouse gas emissions (GHGs), Health (H),Ecosystem (E) **Valuation Examples** **($AUD 2010)** • GHG: vary from $5.94 to $177.43/tonne CO_2 • WTP to avoid waterway degradation 184.73/person/yr - *Thomas et al. (2002)*
WASTEWATER RECYCLING	
• Reduced degradation of receiving waters. (Collection and Treatment Stages (+,↓, ◙)) • Additional water resource available to drought constrained farmers and other industries. (Collection and Use Stages (+,◙)) • Risk of soil contamination. (Use Stages (-,↓, ◙)) • Contamination risks and associated health concerns. (Treatment and Use Stages (-,◙)) • Risk of cross-contamination and consequent illness. (Use/ Distribution Stages (-,◙)) • Low levels of community acceptance for 'high-contact' uses, which may lead to feelings of disempowerment. (Use Stages (-,◙)) • Additional nutrients found within recycled water may serve as potential sources of fertiliser for agricultural uses. (Use Stages (+,◙)) • Increased capacity for maintenance of 'green spaces' throughout droughts – amenity and recreational benefits. (Use Stages (+,◙)) • Disposal of concentrate (a by-product) may lead to environmental degradation and high transport requirements. (Waste Management Stages (-,↓, ◙))	**Main externality types** Water Quality (W.Q),Production (P), Health (H),Non-Use (N.U.) **Valuation Examples** **($AUD 2010)** • Cost of a visit to emergency room $488.52 - *Dixon (1998)* • WTP , $70.35 increase in annual household water costs for recycled water with high contact uses *Gordon, Chapman and Blamey (2001)* • $1073/tonne for average annual point source phosphorus load reduction - *Alam, Rolfe and Donaghy (2006)*

KEY EXTERNALITIES	
DAMS	
• Ecosystem degradation – mostly through; decreased floodplain productivity, altered sediment throughput, altered hydrologic regimes, reduced downstream flows and runoff, and initial inundation of surrounding areas. (Construction/Inundation and Collection/Catchment Management Stages (-, ↑, ↓, ◙)) • Inundation leads to displacement and potential degradation of cultural and heritage sites/values. (Construction and Inundation Stages (-, ↑, ↓, ◙)) • Biodiversity decline, primarily due to the impacts of inundation, altered hydrologic regimes, and the changes/blockage to migration routes. (All Stages (-, ↑, ↓, ◙)) • Dam habitats are often conducive to the breeding of pest species. (Storage Stages (-, ↑, ↓, ◙)) • Provision of recreational opportunities – boating etc. (Storage Stages (+,◙))	**Main externality types** Ecosystem (E),Biodiversity (B) **Valuation Examples** **($AUD 2010)** • WTP $57.54/person/yr to improve environmental flows to rivers - *Blamey, Gordon and Chapman (1999)* • WTP 4.40/person/yr to preserve fish species - *Straton and Zanden (2009)* • WTP to avoid waterway degradation 184.73/person/yr -*Thomas et al. (2002)*
DESALINATION	
• Higher energy and GHG emissions compared to other options. (All Stages (+,◙)) • Potential contamination of aquifers. (Construction and Collection Stages (-,↓, ◙)) • Loss of open coastal ecosystems which can result in decreased tourism, recreational space and coastal amenity. (All Stages (-, ↑, ↓, ◙)) • Decreased local hydrogeography. (All Stages (-, ↑, ↓, ◙)) • The release of brine results in degraded ecosystems and biodiversity in the surrounding area. (Waste Management Stages (-,↓, ◙)) • The construction and laying of pipes and outfalls can physically damage the surrounding ecosystems. (Construction Stages (-, ◙))	**Main externality types** Ecosystem (E),Biodiversity (B),Greenhouse Gases (GHG) **Valuation Examples** **($AUD 2010)** • GHG: vary from $5.94 to $177.43/tonne CO_2 • Commercial Fishing in Moreton Bay worth $46.8 mill/yr - *Taylor (2005)* • WTP $29.38 per recreational beach visit, per person - *Walpole (1990) in Taylor (2005)*
GREYWATER REUSE	
• Low energy requirements. (All Stages (+,◙)) • Benefits to agricultural productivity, in some cases, as the greywater can serve as a source of additional water for irrigation and higher nutrient levels can reduce fertiliser requirements. (Use Stages (+,◙)) • Potential to negatively alter soil structure. (Use Stages (-,↓, ◙)) • Risk of disease transfer. (Treatment and Use Stages (-,↓, ◙)) • The uptake can create savings of fresh water resources. (All Stages (+,↓, ◙)) • Reduced effluent to waterways can create ecology-related benefits, e.g. decreased nutrient loads and decreased erosion. (Collection Stages (+,↓, ◙))	**Main externality types** Production (P),Energy (En),Health (H) **Valuation Examples** **($AUD 2010)** • $8 980/t to reduce diffuse source nitrogen loads per year - *Alam, Rolfe and Donaghy (2008)* • Cost of a visit to emergency room $488.52 - *Dixon (1998)* • WTP for river protection for future generation $103.31/person/yr *Sanders et al, (1990)*
GROUNDWATER SUPPLY	
• Groundwater has the potential to cause severe damage to terrestrial and aquatic ecosystems, primarily as it alters the flow regimes. (All Stages (-, ◙)) • Alteration to water table levels and aquifer levels and water quality. (Extraction Stages (-,↓, ◙)) • Subject to contamination risk from natural sources/substances (e.g. arsenic), old landfills, storage sites and industrial sites. (All Stages (-,↓, ◙)) • Altered flow regimes can lead to decreased biodiversity, especially to vegetation, macrophytes and karst-dwellers. (Extraction Stages (-, ◙)) • Loss of cultural heritage associated with the affected water resources. (All Stages (-, ◙))	**Main externality types** Ecosystem (E),Biodiversity (B),Non-Use (N.U.) **Valuation Examples** **($AUD 2010)** • WTP $6.98 – 175.98/person/yr per species preserved - *Nunes and van den Bergh (2001)* • WTP for water recreation $31.25 - *Green and Tunstall (1991)* • WTP $29.38 per recreational beach visit, per person - *Walpole (1990)*

5.1 Data Limitations

To the authors' knowledge, this report is unique in providing a systematic guide to externality analysis and its incorporation in strategic decision-making for natural resources – especially in terms of its focus upon water and the Australian context. 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.

Specific data limitations affecting the efficacy compendium include:

- The general **lack of knowledge about biodiversity and ecosystem impacts** of the water servicing options. This was especially relevant where the technologies are new and long-term effects are largely unknown. It is also relevant to biodiversity, as there are vast numbers of species which are newly discovered or subject to little previous research. This uncertainty and lack of long-term knowledge constitutes a significant data limitation of this study.
- **Externality and impact research is often weighted towards the political agendas** at the time of publication. For example, as water recycling is currently a controversial issue, it is subject to a plethora of research, specifically looking into public acceptance and water quality issues. Alternatively, dams (which may still be subject to contamination and acceptance issues) had few publications relating specifically to contamination, and therefore have tended to avoid such careful public scrutiny. This is possibly because they are not a new technology and people feel more assured regarding their impacts due to their long history. An important implication is that options that are subject to controversy at the time may appear more problematic due to research revealing a more extensive range of negative externalities.
- Limited data exists on **how water servicing options impact indigenous communities**.
- There is a **pronounced paucity of research and data on the decommissioning impacts of all supply options reviewed**. This is an important life-cycle stage (with the potential for serious externalities) and it is unfortunate that there is so little data available in this area.
- There is also a **general lack of published life cycle assessments** (LCA) and other externality analyses relating to water servicing options. Information from appropriate LCA and other studies would provide a valuable input into this type of research and be consistent with integrated water management approaches.[3]
- There is very little in the way of primary research and data from SE Queensland relating to the monetary values (and, indeed, the biophysical extent) of externalities associated with water servicing options in the region.
- Despite increasing acceptance in policy and planning areas, there have been few studies that explain and exemplify the methods and application of externality analysis and valuation to support decision-making and management of water and other related resources.

These data caveats are significant and should be acknowledged in the application of the compendium results.

It is recommended that research be supported to specifically address some of these key areas. Inter-disciplinary frameworks (as adopted in this report) have the distinct advantage of covering and linking biophysical and socio-economic phenomena and providing integrated scientific information required for policy makers and water management practitioners.

More serious conceptual and data limitations confront the process and application of externality valuation (particularly for health related and non-use valuations). A number of these limitations are described below.

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[3] Two exceptions from the Australian context include Cook,Tjandraatmadja et. al. (2009) and Sharma, Gray *et al.* (2010).

5.2 Economic Valuation – Some Critical Issues

Whilst there is growing support for the methodologies framed in this compendium (note the widespread credence and impact of the Stern Report in 2006), there is also considerable scepticism and diffidence regarding externality valuation. This tends to focus upon contentious issues linked to valuation concepts, assumptions, and the valuation procedures. It is likely, however, that even those opposed to any form of externality valuation will find Section 3 useful as it provides a systematic and extensive means of quickly identifying externalities associated with water servicing options.

5.2.1 Discounting

Discounting is relevant to this study in at least two ways. Firstly, it is used in the calculation of some of the externality valuations provided, for example, for the social cost of carbon. Thus, the estimated values are often dependent upon the discount rate adopted in the study concerned. Secondly, it is often used when the valuation data are applied in decision making frameworks, such as cost-benefit analysis. Discounting aims to adjust all the costs and benefits associated with an action (in this case, the adoption of a particular water supply option) to current dollar values. Thus it converts all costs and benefits regardless of when in time they occur. This is intended to enable comparison of costs and benefits over extended periods of time. As a result, it converts costs and benefits into present value (PV) using a process which is the obverse of 'compounding' as commonly applied to interest rates. Accordingly, the discounting rate will determine the extent to which costs and benefits **now** are greater than those occurring in the **future**. It thus impacts upon intergenerational equity.

Discounting is an element of valuation which has been heavily criticised. The discounting rate will have crucial impacts on the overall 'sustainability of water management decisions (Birol, Koundouri and Kountouris 2010, p.839). Adopting 'best-practice' discounting rates is often a controversial move as, most often, discounting rates which favour decisions with high short-term benefits are chosen over decisions which exhibit long-term benefits (Hanley 2001, p.110). As a consequence, inappropriate discounting rates can undermine key sustainability principles of long-term planning and intergenerational equity (Birol, Koundouri and Kountouris 2010, p.844). They do this by making the net short-term benefits of a certain action seem greater (Spash 1994, p.29). Within the field of ecological economics, there is growing perception that to do anything other than the application of zero or negative rates of pure time-preference is unsustainable (Birol, Koundouri and Kountouris 2010, p.844).

5.2.2 Some Other Conceptual and Methodological Problems with the Economic Valuation of Externalities

Valuation data is useful for water practitioners as it enable the comparison of costs and benefits across options. Numerous valuations of water servicing-related externalities can be located in existing published research. These values can be fed into decision making and policy processes to assist in sustainable water management. In view of the conceptual and theoretical problems associated with the economic valuation of externalities, caution must be taken when applying such data as the cornerstone of policy formulation. However, there are promising valuation techniques that are growing in popularity and sophistication and which feature high levels of community deliberation and participation (for example, citizen's juries and consensus conferences). These can potentially bypass some of the problems associated with more traditional valuation methods (Farber, Costanza and Wilson 2002). Economic criteria are only one dimension of the information base that should be used in decision-making for sustainable water management.

Some examples of the problems associated with valuation processes are listed below.

1. Existing values are disparate.

The existing valuation estimates for the same externality effects are disparate and there are difficulties in the aggregation of existing costs (refer to the valuation tables in Section 4). Accordingly, there are significant limitations in the adoption of these methods as a basis for sustainable water management.

2. High levels of uncertainty within the valuations.

Valuations are subject to the uncertainties present within the impact dose-response prediction process and the technical and scientific basis of water servicing options. Often this uncertainty is not made explicit when presented to decision makers. For example, values do not always reflect the scarcity of the resource in question when its scarcity is uncertain or those valuing it have limited awareness or knowledge (Farber, Costanza and Wilson 2002, p.380). For this reason, values should be used with caution.

3. Underlying flaws in the economic assumptions of valuation processes.

There are underlying flaws in the economic assumptions of valuation processes. This viewpoint is supported by four key arguments outlined below.

Firstly, when market prices are used to ascertain values there can be inherent problems. Should existing prices be applied, the market in which they are determined needs to be analysed as prices may not be representative if the market is "imperfect", ie, subject to monopolies or where consumers lack complete information or expectations about future supply and impacts (Matthews and Lave 2000, p.1390).

Secondly, people buy goods for their ability to meet certain desired characteristics. Thus, technological inability to substitute these characteristics may restrict the margins within which environmental attributes and services are able to be measured (Farber, Costanza and Wilson 2002, p.378).

Thirdly, valuation involves the application of economic theory which assumes that individuals know exactly what their preferences are, and therefore are qualified to accurately state their WTP (Jaeger 2005, p.234). However, people are often not adequately informed to be able to value the costs and benefits of water management decisions. For example, it is unlikely that the public could effectively value the impacts of a 20% increase in nitrogen loads to Moreton Bay without detailed knowledge of the implications (something that would probably be elusive even for experts in the area).

Finally, there are often inconsistencies between people's actual behaviour and the economic models that predict their behaviour (Jaeger 2005, p.234). The economic theory behind valuations can be skewed when people do not act as expected in the conventional "rational optimiser" model (Jaeger 2005, p.234). Evidence throughout psychology and experimental economics has indicated that people do not always act in a self-interested way and sometimes demonstrate cooperative or even altruistic behaviours in valuation experiments. These behaviours may indicate serious shortcomings for valuations as accurate measures of social well-being and suggest there may be aggregation problems.

4. Willingness to Pay studies may not be accurate, acceptable or truly representative.

WTP is not always accurate, acceptable or truly representative. Few studies have questioned the validity and legitimacy of CV through engaging with respondents post survey to check that the respondents felt their views were able to be adequately and accurately expressed through the survey format. Clark, Burgess and Harrison (2000, p.45), from the University College London, conducted an extensive study to explore how participants felt, post-CV, about CV surveys and their ability to reflect the participant's values. Their study presented the results of a qualitative study, which explored the opinions and experiences of respondents (post-participation) in a CV study on a particular conservation issue in the UK. The findings highlighted fundamental flaws in the WTP estimates provided in the initial study (Clark, Burgess and Harrison 2000, p.45). Sources of error included:

problems in contextualising the scheme and what it would be worth in monetary terms; an inability to consider the issue separately from surrounding conservation issues; and a pervasive opinion that their feelings were not able to be effectively conveyed through pricing (and hence, the somewhat patronising nature of the CV exercise) (Clark, Burgess and Harrison 2000, p.45, p.60). The results also demonstrated feelings of frustration and the rejection of CV as an acceptable means of representing public values and perspectives as the figures provide little substance upon reflection (Clark, Burgess and Harrison 2000, p.60). Some quotes from the study (pp.52-54) reflect these notions well:

- *"Someone has to make decisions but it shouldn't be monetary"*
- *"We cannot put a price on nature. It's priceless"*
- *"Nature is not ours to sell"*
- *"I struggled with this money business…"*
- *"The money I agreed to pay is probably not a good measure of what preserving Pevensey Levels is to me. It's what I can afford bearing in mind all the other charities I support"*
- *"It's difficult to quantify and difficult to compare with these other areas that concern me. You can't put a money figure on nature"*

These reports reveal a fundamental problem with the use of WTP – what people want from a societal point of view may not necessarily be reflected in their stated preferences or valuations (Jaeger, 2005, p.234).

5. Values are anthropocentric.

Economic valuations only reflect the contribution of goods or services provided to humans or perceived to contribute to ecosystems through human understanding (Bockstael *et al.* 2000, p.1385). Thus, valuations are fundamentally anthropocentric. Ecological, social and economic values are often at odds with one another (Farber, Costanza and Wilson 2002, p.387). For example, timber only reflects a portion of the full social and ecological values of a tree.

6. Valuations are context specific.

Economic valuations are specific to the context in which they are made; specifically, the starting or reference state, the relation of an option in relation to others, and the identity of the participant (Bockstael *et al.* 2000, p.1385). Values are derived from an individual's (through WTP) or society's (through existing market prices) perceptions and preferences. Values will vary across belief systems, culture, societal trends, mood and life experience.

7. WTP can exceed available funds when aggregated.

If the WTP costs given in many studies are aggregated across regions, they become logically inconsistent as the economic values provided, when pooled, exceed the actual available funds of the region (Bockstael *et al.* 2000, p.1387). Thus, assessment should be made not only in terms of personal financial constraints but also with regional constraints.

To conclude, valuation data are useful for water practitioners as they enable the comparison of a more complete range of costs and benefits across options (including long-term and community-wide effects). Numerous relevant valuations exist in environmental economic literature. These values can be fed into decision making and policy processes to assist in sustainable water management. However, caution must be taken when applying the valuation estimates given the limitations of underlying concepts, assumptions and methods, and significant variation in appropriate geographic and spatial contexts.

6. CONCLUSIONS

Decision-making directed towards sustainable resource management and triple bottom line 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 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, p 7).

The compendium provided in this report is supported by the simple externality analysis (SEXTAN) methodology outlined in the companion report (Daniels and Porter 2012).

The report presents the results of a detailed survey and review of the externalities, and associated costs and benefits, based on an indicative range of water servicing options that are being implemented or considered for ensuring secure and sustainable water for the SEQ region. The research undertaken in this report builds upon existing frameworks developed for the analysis and policy assessment of externalities related to water (e.g. Taylor and Fletcher 2005; Sharma, Grant, Grant, Pamminger and Opray 2009; and Young 2000) and extensive databases of generalised externality economic valuations such as Environment Canada's EVRI (the Environmental Valuation Reference Inventory) and the New South Wales EPA's ENVALUE environmental valuation database.

The first major data set presented (in Section 3) is a systematic tabular summary of all significant externalities associated with the seven major options considered. 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. "greenhouse gas 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. Section 3 also provides some detailed description of the technical nature and impacts of each option under study.

In the second major data set (in Section 4), 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 Section 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, is also included in Section 5.

As noted, the background research has been targeted at a range of options relevant to strategies being considered for SEQ. However, the compendium of water-related externalities 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 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. Failure to factor in externalities, such as those identified in this compendium, may lead to the misallocation of resources and increased levels of damage to society and the natural environment in which it is embedded (Rein 1999).

To the authors' knowledge, this report is unique in providing a systematic guide to externality analysis and its incorporation in strategic decision-making for natural resources – especially in terms of its focus upon water and the Australian context. 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.

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APPENDIX A

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