Life Cycle Assessment of the Gold Coast Urban Water System

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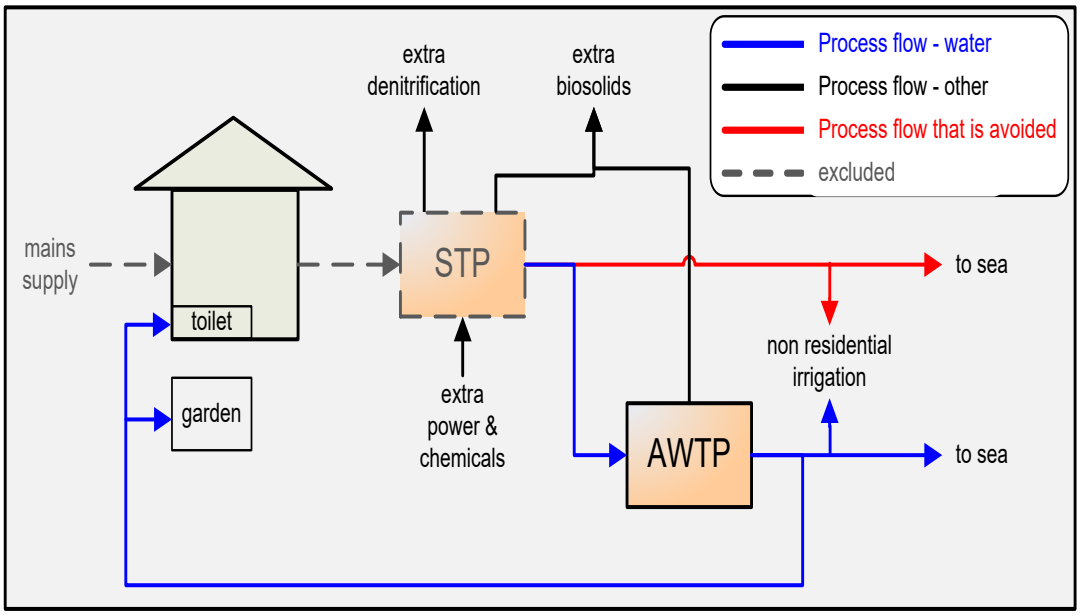
September 2011



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

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FOREWORD

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

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

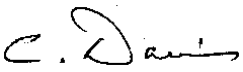
As the largest regionally focused urban water research program in Australia, the Alliance is focused on water security and recycling, but will align research where appropriate with other water research programs such as those of other SEQ water agencies, CSIRO's Water for a Healthy Country National Research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

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

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

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

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



Chris Davis
Chair, Urban Water Security Research Alliance

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EXECUTIVE SUMMARY

Rapid population growth and recent drought pose significant challenges for the urban water system in South East Queensland (SEQ), and will likely mean substantial change to the way water supply and wastewater services are configured and managed. There exists a need for systematic assessment of the tradeoffs associated with choosing between alternative approaches to meeting these challenges.

The Life Cycle Assessment (LCA) methodology applies quantitative rigour to options analysis, taking a long term view across a broad range of environmental impacts. LCA has been used to inform urban water cycle planning elsewhere in Australia and internationally. This study represents the first comprehensive application of LCA across the wide range of water supply and wastewater infrastructure options being considered in SEQ.

Study Objectives

The objectives of this study were to provide information and guidance on:

1. the greenhouse gas risk profile of urban water system infrastructure;
2. the spread of environmental impacts associated with urban water system infrastructure, and opportunities to reduce these impacts;
3. environmental tradeoffs involved in choosing between alternative water supply options;
4. metrics available for including a broad range of environmental issues into quantitative analysis of urban water systems; and
5. key data gaps that should be priorities for more detailed research.

Study Overview

To explore the implications of future changes in the way that water is supplied to urban water communities, two scenarios were considered for the provision of water supply and wastewater services to urban communities in the Gold Coast region of SEQ. The infrastructure considered under each scenario was limited to those water supply and wastewater infrastructure types that are in use, or have been considered for use, at the Gold Coast.

The 'Traditional infrastructure mix' was based on the water supply and wastewater infrastructure in operation at the Gold Coast during 2007/08. This scenario included:

- dam sourced mains water supply via conventional Water Treatment Plants, supplemented by rainwater tanks on ~30% of existing houses; and
- sewage collection and treatment (four STPs), utilising 20% of secondary treated effluent for non-residential (mostly irrigation) reuse, and 100% of biosolids for agricultural reuse.

A 'Future infrastructure mix' was also defined, incorporating four alternative approaches to urban water supply. This included examples of the most prominent non-traditional water supply options being considered for SEQ. The additional infrastructure included for the 'Future infrastructure mix' was:

- additional centralised water supplies from the Tugun desalination plant;
- additional centralised water supplies from an indirect potable reuse scheme delivering tertiary treated wastewater to the local water supply dam;
- households in the Pimpama STP catchment being provided with Class A+ reticulated water for toilet and external uses, along with a 5,000L rainwater tank to supply laundry demands;
- all other (non-Pimpama) new households having a 5,000L rainwater tank that supplies toilet, laundry and external uses; and
- all other (non-Pimpama) new households serviced by new sewage and STP infrastructure equivalent to the conventional STP infrastructure of the 'Traditional' scenario.

Methodology

The approach used to compare these two infrastructure sets was:

- *scenario definition* - define the water balance underpinning each scenario;
- *inventory generation* - collect data on the construction and operations of the infrastructure involved in each scenario, summarising the flows into and out of the system; and
- *impact assessment* - calculate a set of environmental impacts associated with these inventory flows.

Scenario Definition

The scenarios were based on assumptions of average household water use generated from Gold Coast data for 2007/08. For households serviced only with mains water, this was set at 415 L/hh/d. Households with additional supplies from rainwater tanks or Class A+ water were assumed to use 454 L/hh/d. The same water demands were used for both scenarios so as to focus specifically on the implications of different infrastructure options.

The 'Future infrastructure mix' scenario involves a substantial increase in total water supply capacity, and the population serviced by this scenario was also increased so as to maintain a water supply - demand balance. Table 1 summarises the water balance for the two scenarios under consideration, illustrating the contribution made by each different urban water supply source.

Table 1: Water supply balance for each scenario.

	Traditional infrastructure mix	Future infrastructure mix
Households	**222,000**	**570,235**
Water use[1] - total (ML/d)	**140**	**377**
water use[1] - residential	98	262
water use[1] - non residential	42	115
Water supply - total (ML/d)	**140**	**377**
dam supplies - environmental	137	141
dam supplies - IPR	--	44
seawater desalination	--	125
rain water (household tanks)	3	64
Class A+ residential	--	4

1. including allowance for mains distribution losses

Inventory Generation

Data was collected and/or modelled for the construction and use of the infrastructure items included in each scenario. Construction inventories were extrapolated from other studies where local data was not readily available, and were annualised based on estimates of equipment lifespan.

Modelling of the operations phase captured all key operational inputs (e.g. chemicals and power) and outputs (disposal or reuse of wastewater and sludges), and was based wherever possible on actual operating data. Inventories were generated for 1 year of operation of the infrastructure mix for each scenario. Uncertainty distributions were applied to all key operating parameters, so as to account for the significant uncertainties involved with many of the assumptions used.

Data for second order inventories (e.g. chemicals manufacture) were taken from available inventory databases.

Impact Assessment

The chosen set of impact categories was based on the latest international developments in LCA impact modelling, modified for relevance to this particular study. Each indicator implies the potential for

environmental impact, rather than attempting to predict actual environmental damage. Included were *Freshwater Extraction*, *Eutrophication Potential*, *Ecotoxicity Potential (Marine, Freshwater and Terrestrial)*, *Global Warming Potential*, *Ozone Depletion Potential*, *Fossil Fuel Depletion*, and *Human Toxicity Potential*. Despite the relevance of urban water systems to the global phosphorus balance, a *Minerals Depletion* impact category was not included as phosphorus is poorly represented in the available models.

Analysis was undertaken in three stages:

1. The key sources of environmental impact were mapped, so as to identify the major contributors and most significant points of uncertainty;
2. The environmental tradeoffs involved in shifting towards the 'Future' infrastructure mix were considered; and
3. A direct comparison was made across the alternative water supply options that are being considered for use in SEQ.

Impacts of the Urban Water System

Dam water use for the Gold Coast region was the dominant contributor to the *Freshwater Extraction* results, with 'virtual' water use from infrastructure construction or power use being negligible. The *Freshwater Extraction* benefits attributed to the existing Class B reuse system were only small.

The major source of *Eutrophication Potential* was the nutrient load in STP effluent discharged to the sea, however nutrient losses from biosolids application (to farms) could potentially account for 20% of the total nutrient flux to receiving waters. Reduced fertiliser use only partially offset this contribution from biosolids, as it was assumed that a relatively small portion of the biosolids nutrients were available for uptake by crops. This highlights that unless nutrient recycling can achieve effective fertiliser offsets, it risks transferring the point of nutrient discharge from coastal to rural settings. Future studies should give more careful consideration to the potential losses from land applied nutrients, as this is an area of considerable uncertainty for quantitative analysis.

Wastewater and biosolids flows accounted for the majority of the *Ecotoxicity Potential* results. Biosolids metals loadings to agricultural soils contributed more than 90% of the *Terrestrial Ecotoxicity Potential* (TEP), and more than 60% of the *Freshwater Ecotoxicity Potential* (FEP) assuming a portion of the metals are transferred to adjacent streams over the long term. Residual chlorine and metals in STP effluent discharges to the sea contributed more than 50% of the *Marine Ecotoxicity Potential* (MEP). In most cases, organic micropollutants in the various wastewater streams made insignificant contributions to the ecotoxicity results. These findings are subject to important data limitations and methodological concerns associated with the toxicity modelling for the three contaminant groups (chlorine, metals and organics).

Substantial indirect sources of MEP were also noted, particularly associated with transport fuel use (>25% of total MEP). Trucking of biosolids is the major transport inventory item across the full life cycle of the urban water system, with the long distance transport of water and wastewater treatment chemicals also significant. Chemicals manufacture made a large (19%) contribution to the FEP of the 'Future infrastructure mix' scenario, with the responsibility spread across chemicals used for mains water treatment, water reuse and the desalination plant. Power generation is a major contributor (28%) of total *Human Toxicity Potential* (HTP) for the 'Future' scenario. In contrast to the ecotoxicity results, the manufacture of construction materials is the major source of HTP. Limitations with the available toxicity model prevented a thorough assessment of the HTP associated with important aspects of the water system operations (e.g. WTP disinfection byproducts, mixing of treated wastewater into mains supply dams).

Power use contributes 54% and 72% of the *Global Warming Potential* (GWP) for the 'Traditional' and 'Future' scenarios respectively. The increase reflects the energy intensive water supply options included in the latter, particularly from the sea water desalination plant. Despite this, the wastewater treatment sector still makes the biggest contribution (39%) to GWP in the 'Future' scenario. While sewage treatment power use at the Gold Coast is typical of other STPs across SEQ, it is nearly

doubled by the high energy pumping requirements for sewage collection and final wastewater disposal at the Gold Coast. Power use is also the major cause of *Fossil Fuel Depletion* (FFD) across the water system life cycle.

The adoption of non-traditional water supply technologies for the 'Future infrastructure mix' meant this scenario had a lower per-capita FEP and *Aquatic Eutrophication Potential* (AEP). This is a direct result of the key legislative drivers to address the environmental challenges (environmental flow management, and STP nutrient discharge) that have traditionally been the dominant priority for urban water managers. The downside was significant increases in the per-capita GWP, FFD, FEP and HTP associated with the urban water system, largely because of the power and chemicals intensity associated with the new water supply systems. There were also large increases in MEP, TEP and *Ozone Depletion Potential* (ODP) caused by the population growth associated with the 'Future infrastructure mix' scenario.

The results of this study were benchmarked against estimates of the total impacts associated with the Australian economy, indicating the contribution made by the urban water system to the overall Australian environmental burden. The biggest individual contributions were associated with freshwater use, wastewater nutrients, N_2O emissions (because of their ozone depletion potential), and pollutants (metals, organics, chlorine) in biosolids and wastewater discharges.

While the results are subject to large data and methodological uncertainties, they do focus attention on those parameters that are likely to be the most important from the broader perspective of Australian society. This suggests that future pressures for environmental mitigation by the urban water sector are likely to be spread across a wider range of issues than has traditionally been the case. It also confirms that greenhouse gas emissions should not be considered an adequate proxy for the range of important environmental externalities associated with urban water system operations.

Comparison of the New Water Supply Options

For the four alternate water supply options (Class A+ reuse; Indirect potable reuse; household rainwater tanks; sea water desalination) of the 'Future infrastructure mix', the environmental implications of each were directly compared so as to provide a more generic evaluation of the tradeoffs involved in a choice between them. The results were broken down to identify the points of difference, and this analysis could directly inform preliminary estimates for options comparison in different case studies.

The differences across the four scenarios in *Freshwater Extraction* and *Ozone Depletion Potential* were negligible when considered in the context of the overall impacts associated with the Gold Coast 'Traditional infrastructure mix'. However, substantial differences were apparent for all other impact categories.

The indirect potable reuse (IPR) system delivers substantial net reductions in AEP and MEP, although it shifts a portion of the toxicity burdens to freshwater ecosystems. The Class A+ reuse system achieved a much smaller AEP benefit because of the low recycling rate that underpinned the analysis in this study. It is notable that TEP and FEP impacts were caused by redirecting key pollutants to land application via wastewater and biosolids reuse. Because of key design constraints requiring the Pimpama AWTP to treat all secondary effluent to Class A+ standard, the Class A+ scenario greatly increased the total marine emission of chlorine residuals and therefore incurred a substantial increase in MEP. When these constraints were removed from the analysis, the impacts associated with the Class A+ system were greatly reduced.

Even with the design constraints imposed, the Class A+ system had the lowest GWP and FFD of the four scenarios. Power use and chemicals use (particularly for the two recycling systems) were the main cause of GWP and FFD in all cases. Analysis with the default assumptions showed that seawater desalination had the highest GWP and FFD of the four scenarios. However ranking the results for the rainwater tank scenario is made difficult by the substantial uncertainties involved in predicting the long term energy burden of a large number of rainwater tank installations. Sensitivity analysis showed that the energy burden of rainwater tanks could vary from much lower than that of recycling systems, to much higher than that of seawater desalination.

Conclusions and Recommendations

- While the analysis was focussed on Gold Coast, specific infrastructure options, the results and conclusions are largely informative to debate on the range of wastewater and water supply options being contemplated across SEQ.
- The impacts associated with infrastructure construction are likely to be of secondary concern for all impact categories other than Human Toxicity Potential. This applied even for the relatively materials intensive rainwater tank and third pipe reticulation systems.
- Wastewater treatment operations are the biggest source of most of the impacts considered, and may offer the greatest potential for reducing the overall environmental burden of the urban water system. Debates on the environmental implications of urban water system planning decisions should focus on more than just the choice between water supply alternatives.
- Wastewater system decision making should include nutrient balances for any land application of biosolids and wastewater because of the potential for significant nutrient transfers to adjacent waterways. The likelihood and implications of any fertiliser offsets should also be considered. Quantifying these fluxes is subject to very large uncertainties, and assessments would be enhanced by guidance on best practice approaches to doing so in the SEQ context.
- Wastewater and biosolids pollutants (chlorine, metals and organics) are the major source of potential ecotoxicity across the infrastructure lifecycle. Discerning the relative importance of these different contaminants is constrained by limitations with the available contaminant data, and uncertainties associated with the available LCA toxicity models. The inclusion of quantitative ecotoxicity analysis in broad spectrum environmental comparisons is warranted, given the dominance of urban water system operations in the ecotoxicity profiles. A number of potential improvements to the LCA ecotoxicity models have been identified, and the merits of undertaking this work should be reviewed by toxicity experts.
- Biosolids transport (through fuel use) and treatment plant chemicals use (through chemicals manufacture and supply) are responsible for substantial indirect contributions to the overall ecotoxicity potential associated with the Gold Coast urban water system. Further investigation should be made into the validity of including fugitive N_2O emissions in inventories of ozone layer depleting substances. While the debate on this question has some way to run, modelling with the best available data suggests that wastewater system N_2O emissions could make a significant contribution to depletion of the ozone layer. This may pose a significant future challenge for the urban water sector, highlighting the need for improved understanding of N_2O emission loads and mitigation opportunities.
- Power use related impacts will increase substantially in the future as more energy intensive water supply technologies are adopted in SEQ. While power use is the biggest source of urban water system greenhouse gas emissions, it is by no means a suitable proxy for the issue. The contribution from fugitive N_2O, CH_4 and CO_2 emissions is subject to large uncertainties, but is also likely to be substantial. Further research is required to identify the most appropriate assumptions for urban water systems analysis, and to identify opportunities for fugitive emissions mitigation.
- Power use is a major point of distinction between the four alternative water supply options considered in this study. Comparing across the scenarios is complicated by the large uncertainties surrounding the energy burden of rainwater tanks, and further research is required into the significance of different factors for rainwater tank energy use. This may also reveal significant opportunities to avoid excessive power use as rainwater tanks are rolled out over SEQ.
- Compared to the simpler water supply options of seawater desalination and household rainwater harvesting, water reuse systems have the potential for delivering substantial collateral benefits through the reduction of wastewater nutrient, chlorine and micropollutant discharges to aquatic environments. However, future comparative analysis should account for their potential to shift the ecotoxicity impacts to different environments.

- The environmental implications of direct reuse systems and household scale rainwater tanks can be sensitive to water supply-demand imbalances because of their direct coupling with specific household end-uses. Where such systems are under consideration, quantitative comparisons of urban water supply alternatives should include sensitivity testing for different end-use demand levels.
- The incorporation of non-traditional water supply technologies in response to growing populations is likely to mean that future pressures for environmental mitigation by the urban water sector will be spread across a wider range of issues than has traditionally been the case. The significance of a number of environmental issues identified in this study demonstrates that greenhouse gas emissions are not an adequate proxy for the range of important environmental externalities associated with urban water system operations.
- LCA provides a number of impact models that may enhance the quality of broad spectrum environmental analysis of urban water systems. A number of recommendations are provided on potential model improvements that warrant further consideration. Urban water systems analysis should also be extended to consider the significance of phosphorus recovery in the context of global minerals resource depletion challenges.
- Use of these impact categories in the decision making process would likely require a normalisation step to provide perspective on the relative significance of tradeoffs involved in any particular infrastructure choice. The best available Australian normalisation datasets for LCA analysis involve substantial data gaps. Further investigation is necessary to determine the significance of this to the prioritisation of environmental issues for consideration by urban water planners.

1. INTRODUCTION

The South East Queensland (SEQ) urban water system has been in a significant state of flux for the past decade. Public demand for improved protection of local waterways has driven large reductions in nutrient discharge to the aquatic environment. Local drought from 2001 to 2009 resulted in severe short term water shortages that focussed planning attention on the need for climate independent water supplies. Forecasts of substantial population growth for the region have brought on longer term planning for additional water supply capacity (QWC 2010).

In response to these challenges, a number of changes have already been implemented. All major centralised water supplies in SEQ are now interconnected via a grid system, allowing integrated management of mains supply to the region as a whole. Key measures to boost mains supply capacity include a seawater desalination plant at Tugun on the Gold Coast, Wyaralong Dam in the Logan River catchment, raising the wall height of Hinze Dam and capacity increases to a number of the region's other existing surface and groundwater sources.

A number of significant water recycling projects have also recently been commissioned. The Western Corridor Purified Recycled Water scheme has the capacity to treat the majority of urban sewage in the Brisbane River catchment to a quality suitable for large-scale direct non-residential reuse. The treatment plants are also capable of providing an indirect potable reuse (IPR) scheme utilising existing water supply dams. In the Pimpama-Coomera region of the Gold Coast, Class A+ wastewater is piped directly to households and industry for reuse in toilets and for outdoor irrigation.

To cope with the large forecast increases in population, the SEQ Water Strategy (QWC 2010) envisages the possibility of additional desalination or IPR systems being installed at different locations around SEQ. In more localised infrastructure planning for new growth areas, consideration is frequently given to the use of Class A+ reticulation schemes and/or stormwater harvesting to supplement mains water supplies.

The other main driver for future infrastructure development is the Queensland Development Code MP 4.2 (2008) requirement that all new households built in SEQ must have some form of on-site water supply that will offset the demand for mains potable water. The legislation allows a small number of possibilities to meet this requirement, and the likely result in practice is that all new houses will typically have a rainwater tank installed to capture roof runoff.

Security of water supply has been the main driver for the adoption or consideration of these alternative approaches. The choice and design of the infrastructure has been influenced by environmental concerns, but arguably this has focussed primarily on the protection of local aquatic ecosystems. Consideration of other environmental externalities often seems patchy, with public debate constrained by a lack of rigorous quantitative information. Furthermore, this debate is often dominated by the single issue of greenhouse gas emissions, with little recognition given to the other possible environmental tradeoffs that might be involved.

Research work through the SEQ Urban Water Security Research Alliance identified the need to investigate a broader suite of possible environmental impacts associated with the SEQ urban water system. This would allow a more comprehensive assessment of the tradeoffs involved with the more varied, and more complex, urban water systems that are under consideration in SEQ. In addition, identifying the main contributors to the environmental impact profile of the existing and future infrastructure would provide a better understanding of opportunities to reduce or avoid these impacts. These two opportunities form the primary goals of this study.

To address these goals, analysis was focussed specifically on the Gold Coast region in SEQ. The geographic limitation was imposed in order to reduce the data collection efforts required, allowing a greater focus on conceptual analysis of issues that will be relevant across the whole of SEQ. The infrastructure options included in this study were specifically chosen to provide insight that is representative beyond the boundaries of the Gold Coast.

The rigorous quantitative analysis required for this exercise has been implemented using the Life Cycle Assessment (LCA) methodology. The final goal of this study was to critique whether this approach can make a useful contribution to the urban water systems planning process.

2. RESEARCH OBJECTIVES

The objectives of this LCA analysis were to:

1. Quantify the Greenhouse Gas emissions profile for key components of the SEQ urban water system.
2. Assess a wider suite of environmental and resource use impacts associated with the life-cycle of existing or planned water system infrastructure at the Gold Coast; and identify key opportunities to reduce these impacts.
3. Identify key environmental tradeoffs involved in decisions between alternate approaches to supplying water to the growing SEQ population.
4. Provide metrics to support quantitative analysis of different urban water cycle options across a broad range of environmental issues.
5. Identify data gaps that should be prioritised for more detailed research in order that quantitative analysis of urban water systems can help deliver more optimal environmental outcomes.

3. REPORT STRUCTURE

The following provides an overview of how these five Research Objectives are addressed by this report. The findings and any associated recommendations relevant to each specific Research Objective are collated in Chapter 5.

The findings for **Research Objectives 1 and 2** are based on comparative analysis of two different sets of urban water system infrastructure. These two scenarios are defined in Sections 4.1 and 4.2. Section 4.3 outlines the data and assumptions underpinning the modelling of each of the infrastructure components. A review of environmental issues covered by LCA is presented in Section 4.4, with details provided on the models used for this study.

Chapters 5 and 6 compare the two scenarios on the basis of these chosen impact categories. Statistical uncertainty analysis is used to inform these comparisons, with Section 4.4 providing some background principles that guided this step. Specifically to address **Research Objective 2**, the results of both scenarios were also normalised against a chosen benchmark that is described in Section 4.6.

Chapter 7 extracts four of the water supply technologies that were considered as part of the urban water system scenarios, and directly compares them using a subset of the impact categories described in Section 4.4. This analysis, combined with learnings from Chapters 5 and 6, is summarised as findings for **Research Objective 3**.

To address **Research Objective 4**, the relevant section of Chapter 5 provides further critique on the merits or otherwise of the impact categories used in the analysis of Chapters 5 to 7. This discussion draws heavily on the background information provided in Section 4.4.

Each of the four sections in Chapter 5 highlight key data gaps and issues that might constrain the implementation of broad spectrum quantitative environmental assessment of urban water systems. Collectively, this forms the output of this study addressing **Research Objective 5**.

4. METHODOLOGY

4.1 System Boundary

This study considered two scenarios for the provision of water supply and wastewater services to urban communities in the Gold Coast region of SEQ. The location and boundary of the Gold Coast district is illustrated in Figure 1.

The two scenarios were:

- A 'Traditional infrastructure mix', which included the dominant water supply and wastewater infrastructure types in use during the 2007/08 period. This is typical of the traditional approach to water supply and wastewater services throughout SEQ and much of Australia.
- A hypothetical 'Future infrastructure mix' which included those infrastructure approaches that have more recently been introduced, or been considered for implementation, at the Gold Coast. This included examples of the most prominent non-traditional water supply options being considered for SEQ. This scenario also incorporates a substantial increase in urban water demand, reflecting the population growth that is occurring in parallel with the construction of new water supply infrastructure in SEQ.

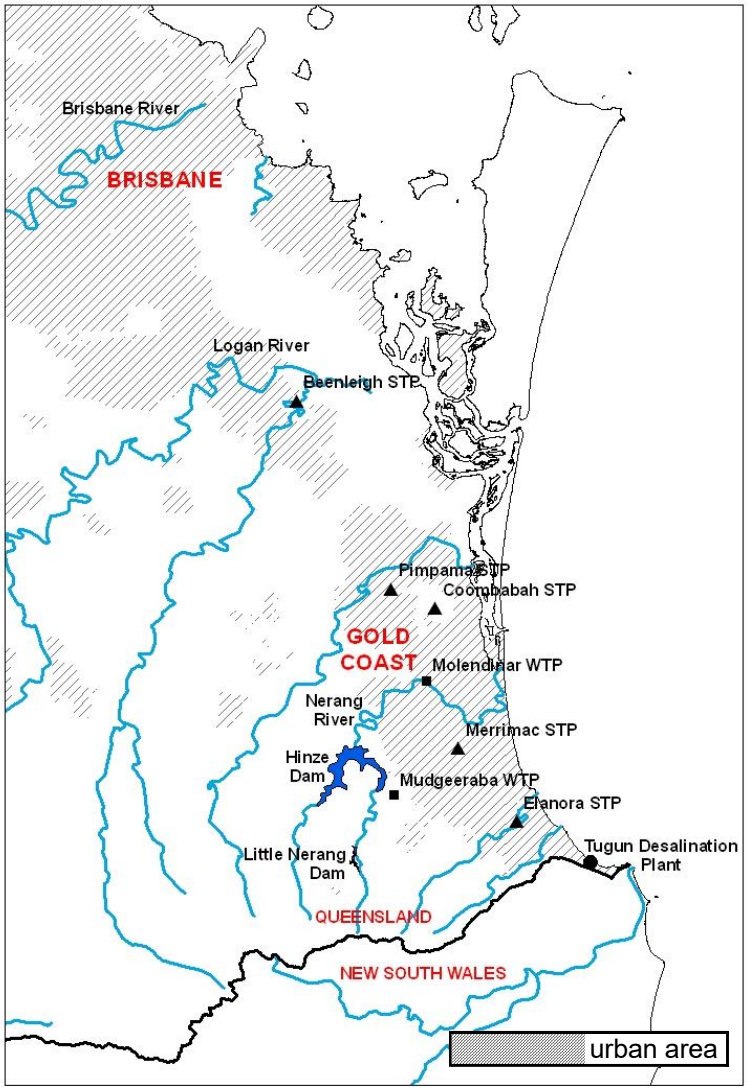

Figure 1: Map of the Gold Coast region.

This study did not assess the implications of incremental future development of new infrastructure, nor consider the implications of any particular development trajectory. Instead, the differences between the two possible infrastructure mixes were explored by comparing the scenarios on the basis that either was fully developed and operating (steady state) over a 1 year period.

The extent of the water supply infrastructure under consideration was, for reticulated supplies, from the supply source to the property boundary. For household rainwater tanks, the infrastructure up to the discharge of the delivery pump was included. Excluded was any other infrastructure inside the property boundary (such as household plumbing or water heating) associated with actual water use. For wastewater systems, all infrastructure downstream of the street level collection point was considered. Wastewater flow balances were based on dry-weather conditions.

The 'construction' and 'use' phases of the infrastructure life-cycle were included in the modelling. The 'construction' inventories for each infrastructure type were annualised based on estimates of equipment lifespan. The 'use' phase captured key operational inputs and outputs, but excluded those associated with infrastructure maintenance. Disposal or reuse of the main process wastes (wastewater and sludges) was modelled. However the disposal of all other materials (e.g. construction items, membranes, rainwater tanks), and therefore any potential for downstream recycling, was excluded from the analysis. Most LCA studies of urban water systems (Gaterell, Griffin et al. 2005; Vince, Aoustin *et al*. 2009) have found the impacts associated with the materials end-of-life phase to be negligible.

The modelling also accounted for the reduced supply and use of fertilisers and irrigation water that might result from the reuse of wastewater and sludges. However no consideration was given to flow on effects such as changes to crop yields, and the implications of such an effect were excluded from the system boundary.

Second-order inventories were included, such as the materials and energy flows associated with the manufacture, processing and/or supply of key inputs (e.g. concrete, chemicals, transport, electricity) and any offsets (e.g. displaced fertiliser use). Third-order inventories, such as the manufacture of the capital equipment used to provide chemicals and electricity, were excluded from the modelling.

4.1.1 Traditional Infrastructure Mix

Figure 2 provides a conceptual overview of the 'Traditional infrastructure mix' scenario. This included the main water supply and wastewater treatment infrastructure in operation during 2007/08 in the Gold Coast district highlighted in Figure 1. The residential population basis for this scenario is summarised in Table. Analysis of this scenario assumed that this population and infrastructure mix would be in place and operating (steady state) for a 1 year period.

The Traditional infrastructure mix comprised:

- Two local water supply dams (Hinze Dam and Little Nerang Dam).
- Two Water Treatment Plants (WTPs) (Molendinar and Mudgeeraba), both using conventional flocculation-filtration-chlorination treatment processes to produce 137 ML/d of mains supply in total. Both plants discharge their waste sludge to the sewer.
- The Gold Coast district mains water reticulation network, supplying urban residential, peri-urban residential and non-residential customers.
- The Gold Coast district sewer network, collecting sewage from urban residential and non-residential customers.
- Four sewage treatment plants (STPs) (at Beenleigh, Coombabah, Merrimac and Elanora) that utilise a mix of biological nutrient removal activated sludge technologies. The majority of the flow is treated in extended aeration-type processes, with only one plant (Elanora) including primary sedimentation, anaerobic digestion and energy recovery from biogas. Practically all the dewatered biosolids from the STPs is trucked without further processing for agricultural reuse.

- On average across the four STPs, approximately 80% of the treated wastewater is discharged to the ocean. The remaining 20% is reticulated through a separate piping network for reuse to a range of non-residential customers (predominantly for irrigation of golf courses and public open spaces).
- A small number of households (16% of total) were assumed to have a rainwater tank connected. Those installed with the construction of new housing (between January 2007 and June 2008) were assumed to be connected to toilet, laundry and external uses as per the Queensland Development Code MP 4.2 (2008) requirements. The remainder were assumed to be installed through retrofit programs and plumbed only for external use.

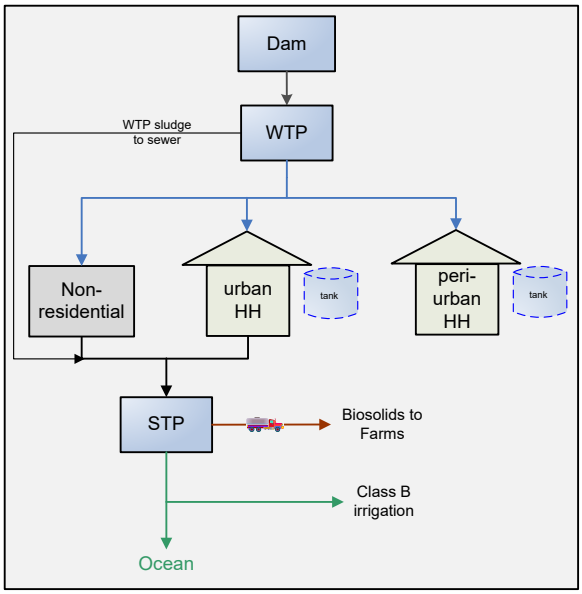

Figure 2: 'Traditional infrastructure mix' scenario.

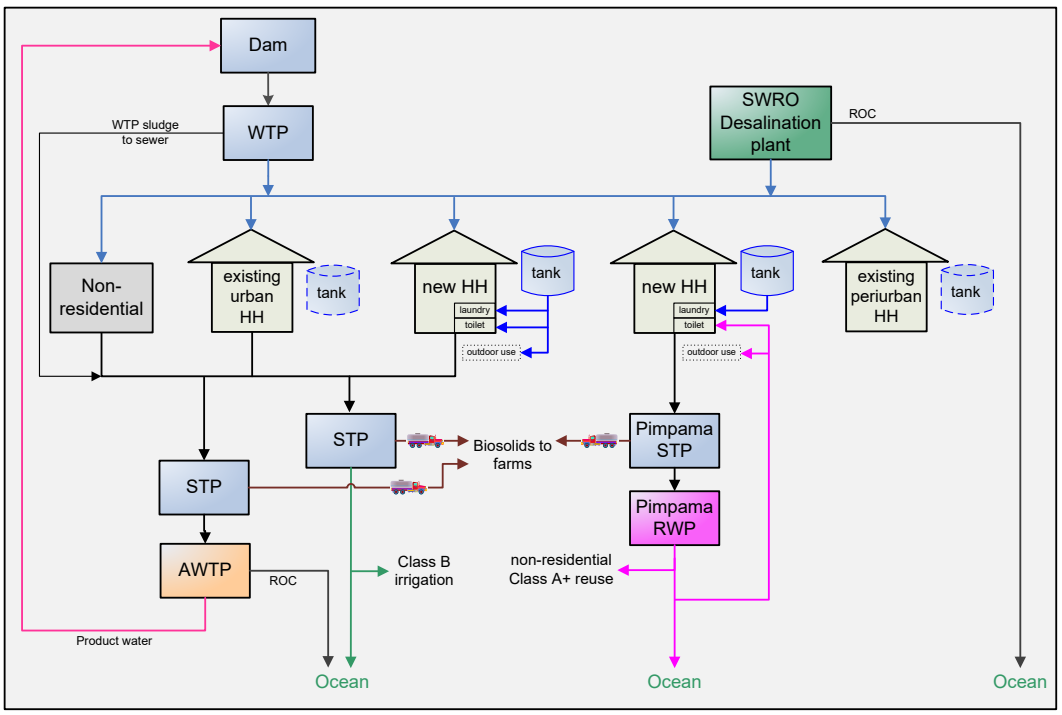

Figure 3: 'Future infrastructure mix' scenario.

4.1.2 Future Infrastructure Mix

This scenario was based on an infrastructure mix that might possibly exist on the Gold Coast at some future point in time. This is not intended to predict the actual evolution of infrastructure development at the Gold Coast. Instead it is a hypothetical choice for the sake of exploring the implications of fundamental changes to the way in which urban water supplies are provided.

The Gold Coast mains supply system has recently been integrated with the SEQ Water Grid, and it is possible that the Gold Coast region will become a net exporter of mains water to other SEQ areas over the long term. Along with an increase in overall water supply capacity, this 'Future infrastructure mix' scenario incorporated a substantial increase in population and total water demand (Table 2 and Table 4). While much of this was assumed to be located within the Gold Coast region, this scenario also involved a conceptual expansion in the urban footprint to the extent required to utilise the additional mains water supplies provided by the new infrastructure. The analysis assumed that this system (population and infrastructure mix) would be in place and operating (steady state) for a one-year period.

Figure 3 provides a conceptual overview of the 'Future infrastructure mix' scenario. The following assumptions outline the mix of infrastructure involved:

- The existing infrastructure as defined in the 'Traditional infrastructure mix' scenario.
- Increased (minor) extraction from the existing dams up to a long term average yield limit of 141 ML/d[1], made possible by the raising of the Hinze Dam wall.
- Over and above this, additional dam extractions facilitated by an IPR system. A recent study identified that the Gold Coast area would be a technically favourable location should any additional IPR schemes be adopted in SEQ in the future (CH2MHill 2008). The key assumptions underpinning the hypothetical IPR system for this study were:
  - advanced treatment of the full dry weather secondary effluent capacity (54 ML/d) of the Gold Coast's largest sewage treatment plant (Coombabah STP), with the product water pumped into Hinze Dam;
  - a similar AWTP process train (chemical phosphorus removal; micro filtration; reverse osmosis (RO); advanced oxidation) to those used for the Western Corridor scheme elsewhere in SEQ; and
  - the reverse osmosis (RO) reject stream treated (including denitrification) then discharged to the sea via the existing Coombabah STP secondary treated effluent discharge pipeline.
- Increased flow through the existing two WTPs, but without the need for additional infrastructure since the total throughput would still be less than the currently available capacity.
- A seawater (RO) desalination plant operating at the full capacity (125 ML/d) of the Tugun plant recently commissioned at the Gold Coast. As per the Tugun plant, potable quality product water is discharged into the existing mains water supply reservoirs, RO concentrate (brine) is discharged to sea through a dedicated pipeline, and sludges are trucked offsite for landfill disposal.
- A portion of the additional sewage generation treated using the STP-AWTP configuration commissioned in 2008/09 for the Pimpama-Coomera catchment of the Gold Coast. This system reticulates Class A+ water to households and non-residential users in the STP catchment via a dedicated 'third pipe' network. While the long term master planning for this area involves further capacity increases (GCW 2004), the Pimpama STP-AWTP throughput for this study was capped at the capacity (17.1 ML/d) of the existing infrastructure. In line with the current operations of the Pimpama plant, it was assumed that:
  - all treated secondary effluent is processed by the AWTP, with product water directed to households (for toilet and external uses) and to non-residential customers;
  - any surplus Class A+ water is discharged to the sea; and
  - all biosolids and AWTP waste sludge are directed to agricultural reuse.

[1] guided by the SEQ Water Strategy QWC (2010). South East Queensland Water Strategy. Brisbane.

- The remainder of the additional sewage generation under this scenario was assumed to be serviced by one or more new STPs. The infrastructure and performance for these were matched to the weighted average of the four STPs included in the 'Traditional infrastructure mix' scenario. It was assumed that the demand for non-residential direct reuse of secondary treated effluent would increase in proportion to the growth in STP throughput, such that the reuse fraction remains at 20%. All biosolids from the new STP operations was assumed to go to agricultural reuse as per current practice.
- Expansion of the mains supply and sewer reticulation networks in proportion to the number of additional houses included.
- All additional (new) households were assumed to have a 5,000L rainwater tank supplying all laundry (cold water only), toilet and outdoor uses. The exception was for those houses also connected to a Class A+ recycled water supply, in which case the rainwater tank was assumed to supply only the cold water laundry demands. It was assumed that no additional rainwater tanks would be retrofitted to existing Gold Coast households.

Table 2: Household numbers for each scenario.

	Traditional infrastructure mix	Future infrastructure mix	Increase
Urban households	**202,000**	**550,235**	**348,235#**
mains supply only[1]	171,894	171,894	0
mains + rainwater tank (for external use)[1]	22,114	22,114	0
mains + rainwater tank (toilet, laundry & external use)[1]	7,992	324,341	316,349
mains + rainwater tank (laundry) + Class A+ (toilet & external)[2]	0	31,886	31,886
Peri-urban households[3]	**20,000**	**20,000**	**0**
Total households	**222,000**	**570,235**	**348,235**

1. connected to mains water supply & conventional STP

2. connected to mains water supply & Pimpama STP-AWTP

3. connected to mains water supply & some with rainwater tanks; not connected to sewerage

 # 250,000 of these were assumed to be within the urban boundary of the Gold Coast district, with the remainder located immediately to the north of this area

4.2 Scenario Water Balances

In order that the comparison illustrate the implications of changes in the infrastructure mix, rather than a mix of consumption patterns, both scenarios assumed the same average household water demand and sewage generation based on an average of 2.6 persons per household. A summary of the household water use and sewage assumptions is provided in Table 3.

The basis for this household water use profile was consumption and supply data for 2008, which is described in more detail in the next section. This period coincided with a level of household water consumption that was notably lower than in previous and subsequent times. It is also lower than the forecasts underpinning the SEQ Water Strategy (QWC 2010). While the choice of a relatively low average household demand had little material effect in most cases, Chapters 5 - 7 note some important implications for the results of this analysis.

Table 3: Average per-household residential water use and sewage generation (L/hh/d).

Toilet	55	L/hh/d
Laundry (cold water use)	78	L/hh/d
Total internal water use	**355**	**L/hh/d**
External use - baseline	54	L/hh/d
External use - extra[1]	39	L/hh/d
Total water use - houses with rainwater tanks or Class A+	**415**	**L/hh/d**
Total water use - other houses	**454**	**L/hh/d**
Sewage generation	355	L/hh/d

1. for houses with rainwater tanks or Class A+ supplies

Table 4 and Table 5 provide an overview of the water balance for both the 'Traditional infrastructure mix' and 'Future infrastructure mix' scenarios. Table 2 summarises the household numbers underpinning the water balance for each scenario. The following sections outline how these water balances were constructed.

Table 4: Water supply balance for each scenario.

	Traditional infrastructure mix (ML/d)	Future infrastructure mix (ML/d)
Water use[1] - total	**140**	**377**
water use[1] - residential	98	262
water use[1] - non residential	42	115
Water supply - total	**140**	**377**
dam supplies - environmental	137	141
dam supplies - IPR	--	44
seawater desalination	--	125
rain water	3	64
Class A+ residential	--	4

1. including allowance for mains distribution losses

Table 5: Sewage balance for each scenario.

	Traditional infrastructure mix (ML/d)	Future infrastructure mix (ML/d)
Sewage generation - total	**108**	**295**
sewage - residential	72	195
sewage - non residential	37	100
Wastewater to reuse - total	**21**	**107**
Class B reuse	21	54
Class A+ reuse	--	7
IPR product water	--	45
Wastewater to sea - total	**87**	**188**
secondary effluent to sea	87	170
tertiary effluent to sea	--	10
AWTP RO reject to sea	--	9
Wastewater disposal - total	**108**	**295**

4.2.1 'Traditional Infrastructure Mix' Scenario

Bulk water supply (residential and non-residential) data for the 2007/08 period were taken from the 2007/08 National Performance Report for urban water utilities (NWC 2009), and were used to estimate the portion of mains supply lost as leaks (8%) in the distribution system. These distribution losses were assigned equally to all mains users on a flow-weighted basis. NWC (2009) also provided the number of households (hh) connected to the mains supply (222,000 hh) and sewage networks (202,000 hh), which were adopted for the 'Traditional infrastructure mix' scenario. The 20,000 households not connected to the sewage network constitute the peri-urban component of the mains water system.

Assumptions on the household mains water use profile were taken from 2008 data for the Gold Coast (Willis, Stewart *et al*. 2009). To reconcile this with the bulk mains supply data for 2007/08, an estimate of the rainwater tank contributions to external water use was required. The amount of rainwater used by Gold Coast houses with a rainwater tank is not well understood, and more detail on the relevant rainwater tank modelling is provided in Section 4.3.4. To close the water balance, it was assumed that all households used an equal baseline amount of water (regardless of source) for external purposes. This baseline was then calculated by adjusting the rainwater tank contributions until a balance was obtained between the mains supply, mains use, and rainwater tank flow estimates. Houses with a rainwater tank were then assumed to use additional rainwater for external purposes, over and above the baseline external usage. The amount of this additional external use was informed by the predictions of Willis *et al*. (2009).

Household sewage generation was assumed to equal total household internal water use. From this, the total residential contribution to sewage flows was estimated. Gold Coast Water provided estimates of the total dry weather sewage flows for the 2007/08 period. Non-residential sewage generation was set as the difference between this and the residential estimate.

4.2.2 'Future Infrastructure Mix' Scenario

The water supply/demand balance for the 'Future infrastructure mix' scenario was based on the following assumptions:

- average household water use profiles were adopted as per Table 3;
- average household supplies from non-mains sources were set for rainwater tanks (see Section 4.3.4) and Class A+ supplies (see Section 4.3.3);
- increased non-residential mains water use in proportion to the increase in total household numbers; and
- all the mains supply infrastructure would run at full capacity for the entire time period of the analysis[2].

The number of additional households (~348,000) for inclusion in the 'Future infrastructure mix' scenario was then calculated, such that total mains demand equalled total supply. Based on previous work undertaken by the study team, it was estimated that there would be approximately 250,000 new households built in the Gold Coast region by 2056. This was used as the estimate for additional houses (under the 'Future infrastructure mix' scenario) occurring within the Gold Coast region, with the remainder assumed to be new households in the high-growth areas to the north (e.g. Logan).

It was assumed that all new households would be connected to the sewer (i.e. that there were no additional peri-urban households). Non-residential sewage generation was increased in proportion to the total number of households, and assumed to be distributed evenly across all STP catchments. Average sewage nutrient, COD and micropollutant loadings were set at the weighted average of the four STPs in the 'Traditional infrastructure mix' scenario. The majority (~316,000) of new households were assigned to the conventional STPs.

The other ~32,000 new households were assigned to the Pimpama-Coomera STP and Class A+ reticulation system. The demand for residential Class A+ reuse was calculated from the average laundry and external household water profiles. The availability of the Class A+ supply was also assumed to induce an additional amount of external water use over and beyond the baseline (Willis, Stewart *et al*. 2009). The demand for non-residential Class A+ recycled water from this scheme was assumed to be 20% of the total throughput.

[2] This is not representative of how such a mains supply system would be managed. However, in the absence of detailed long term water balance models, this assumption was used to enable analysis of the different infrastructure scenarios.

4.3 Data Collection

Inventories of operational inputs and outputs were collected from the best available sources, using local Gold Coast data whenever possible.

The construction estimates captured the material inputs for the physical infrastructure, with the inventories annualised based on assumed equipment lifespans. Preliminary analysis suggested that these would make only a small contribution to the overall impact results. It was therefore considered appropriate to extrapolate construction inventory data from other studies whenever local data was not readily available.

Data for second order inventories (e.g. supply of power, chemicals and construction materials) was sourced from the Australasian LCA Database (Grant 2010) where possible, or otherwise from the Ecoinvent database (Frischknecht et al 2010).

Further details on the data collection for each infrastructure type are included below. A summary of key parameters is included in Appendix A.

4.3.1 Conventional Centralised Water Supply

The Gold Coast district has two major water supply dams (Hinze Dam and Little Nerang Dam), both in the Nerang River catchment. These feed two water treatment plants (Mudgeeraba WTP; Molendinar WTP) using conventional flocculation-filtration-chlorination treatment processes. Mains water is reticulated through an integrated piping network that feeds the entire district. Figure 1 illustrates the location of each dam and WTP. Table 6 and Table 7 summarise key characteristics of the dam and WTP infrastructure.

Appendix A provides the relevant assumptions and data sources for all parameters used in the mains supply modelling. Appendix B provides a summary of the inventory flows, calculated using default assumptions for all inputs.

4.3.1.1 Dam Supplies

Construction inventories for the dams were based on information published by the Hinze Dam Alliance (2007) and Seqwater (2009; 2009).

While fugitive greenhouse gas emissions from the two Gold Coast dams are actively being investigated by others (Grinham 2009; Sherman 2009), there was insufficient data available in time to reliably inform this study. However, indications were that the level of CH_4 emissions from ongoing carbon inputs (e.g. leaf litter) is comparable to the limited available overseas data. Given the relatively high level of forestation in the Gold Coast dam catchments, estimates for dam methane emissions were based on overseas data for a dam in a forested tropical catchment (Delmas *et al*. 2005). Uncertainty data for dam methane emissions was informed by Hall *et al.* (2009), with the large variance chosen to reflect the high level uncertainty associated with this estimate. Fugitive CH_4 and CO_2 emissions associated with the initial inundation of vegetation (at the time of dam construction) were not accounted for.

Table 6: Summary of Gold Coast dams (2007/08).

	Hinze*	Little Nerang
Dam wall construction	earth embankment	concrete
Full supply capacity (GL)	161	7
Surface Area (m^2)	972	49

** Hinze Dam Stage 2*

Dam evaporation losses were not accounted for in this study.

Annual average energy use data for pumping raw water from the dams was provided by Gold Coast Water (GCW), and assumed to have a low variance in line with other pumping assumptions based on empirical data.

4.3.1.2 Dam Water Treatment

Data from Friedrich (2001) and Ecoinvent (Frischknecht *et al.* 2010) were used to estimate the construction inventories for the WTPs. No expansion of the infrastructure was included under the 'Future infrastructure mix' scenario, as the available capacity of the existing plants is sufficient to meet the throughput under the 'Future infrastructure mix' scenario.

Table 7: Summary of Gold Coast WTPs (2007/08).

		Molendinar	Mudgeeraba
Mains supply	(ML/d)	96	41
Treatment process		Floculation; Filtration; Disinfection	Floculation; Filtration; Disinfection
Power use from grid			
- raw water supply	(kWh/d)	99	48
- treatment	(kWh/d)	5,328	1,552
- mains distribution	(kWh/d)	14,558	
Chemical use	(kg/d)	17,639	9,552
- floculation		alum sulphate	alum sulphate
- disinfection		sodium hypchlorite	sodium hypchlorite
sludge generation	(t-ds/d)	2.0	1.3
sludge disposal		sewer	sewer

Annual data for operational inputs (raw water; power, fuel and chemicals use) and outputs (treated water; sludge) for both WTPs was provided by GCW; with uncertainty estimates informed by the variance analysis undertaken for equivalent parameters of the Gold Coast desalination plant (see Section 4.3.3). A portion (30%) of the WTP power and fuel use was assumed to be fixed, with the remainder set to respond linearly to the increased throughput of the 'Future infrastructure mix' scenario.

Sludge wastes from both WTPs are sent to the sewer, and their metals content was estimated from the chemical dosing levels. These metals were accounted for in the STP modelling (see Section 4.3.2), where it was assumed that they report entirely to the biosolids stream.

4.3.1.3 Mains Network Supply

For the water supply networks, GCW provided detailed data on the piping size, length and materials. Construction inventories for the pipe laying were based on the work of Grant *et al.* (2005). For the intermediate reservoirs distributed throughout the network, materials inventories were estimated based on data provided by the Queensland Water Commission (QWC 2009). For the 'Future infrastructure mix' scenario, networks infrastructure was scaled up in proportion to the number of additional households.

Energy use data for mains distribution pumping was provided by GCW, and assumed to vary linearly with flow in order to model the 'Future infrastructure mix' scenario.

An estimate of bulk losses in the mains distribution network was taken from Gold Coast data in NWC (2009), and applied equally to all mains water users. These same assumptions were used for the expanded mains supply of the 'Future infrastructure mix' scenario.

The 2007/08 operating period involved no export or import of bulk mains water from/to the Gold Coast (NWC 2009). However the 'Future infrastructure mix' scenario included ~100,000 households located in the adjoining regions to the north of the Gold Coast, and it was assumed that additional pumping was required to provide mains supplies to these. The power use required for this additional pumping was based on the estimate for SEQ bulk water transfer (north from the Gold Coast) used by Hall *et al.* (2009).

4.3.2 Conventional Centralised Wastewater Treatment

The Gold Coast district had four STPs operating during the 2007/08 period: Beenleigh STP, Coombabah STP, Merrimac STP and Elanora STP. The location of each is identified in Figure 1. These use a mix of biological nutrient removal activated sludge technologies, with only one including energy recovery from biogas. Table 8 summarises key characteristics (based on the default assumptions described below) for each of the four STPs.

Appendix A provides the relevant assumptions and data sources for all parameters used in the STP modelling. Appendix B provides a summary of the inventory flows, calculated using default assumptions for all inputs.

Unless noted otherwise, the assumptions described below were maintained for the expanded 'conventional' sewage treatment capacity under the 'Future infrastructure mix' scenario. As described in Section 4.3.3, modelling for the Pimpama-Coomera STP-AWTP relied on actual operational data for that site.

4.3.2.1 Sewage Collection and Treatment

Detailed pipe length and materials data for the sewerage networks were obtained from GCW, with construction inventories for the pipe laying based on the work of Grant *et al.* (2005). Data from Ecoinvent (Frischknecht *et al*. 2010) was used to estimate the construction inventories for the STPs.

For the sewer network and four STPs, GCW provided 2007/08 operational data covering:

- power, fuel and chemicals use;
- dry weather flows and influent/effluent quality (COD, nutrient and chlorine concentrations); and
- sludge generation rates.

STP operational inventories were generated using linear models for each STP. These models were based on detailed flow, carbon and nutrient balances, and linked process inputs (chemicals and power use) and outputs (grits and biosolids) to key influent/effluent constraints (flow, N, P, COD). Default values for the model input parameters were generated by calibrating the models against the 2007/08 inventory data provided by GCW. Uncertainty distributions were informed by the variance in power use, chemicals use, biosolids flows and wastewater quality data collected for 35 STPs in SEQ (de Haas, Foley *et al*. 2009).

Table 8: Summary of Gold Coast STPs (2007/08).

		Beenleigh	Coombabah	Elanora	Merrimac
ADWF	(ML/d)	10	54	15	29
Treatment system		Bardenpho modified activated sludge extended aeration BNR	Extended aeration BNR	Compartmentalised BNR; primary sedimentation; anaerobic sludge digestion	Compartmentalised extended aeration BNR
WW to irrigation (Class	(%)	20%			
WW to sea	(%)	80%			
Power use from grid - sewage	(kWh/d)	42,269			
- treatment	(kWh/d)	7,359	33,357	12,343	20,559
- effluent distribution	(kWh/d)	463	15,730	5,290	3,780
Chemical use	(kg/d)	1688	146	3158	96
- P removal		alum sulphate	--	ferrous chloride	--
- carbon source		ethanol	--	--	--
- disinfection		UV	chlorine	chlorine	sodium
biogas generation	(ML/d)	0	0	3	0
biogas treatment		--	--	power	--
grit generation	(t-ws/d)	0.4	1.4	0.15	1.0
grit trucked to landfill	(km)	10	20	50	50
biosolids generation	(t-ds/d)	4.5	12.9	4.9	7.5
biosolids trucked to farn	(km)	200	200	200	200
effluent - TN	(mg-N/L)	2	3	10	3
effluent - TP	(mg-P/L)	1	4	3	2
effluent - total chlorine	(mg/L)	0.0	0.5	0.1	0.4

The STP models also calculated fugitive gas emission rates, with uncertainty distributions applied to the most substantive emission pathways. The relevant assumptions were:

- The Gold Coast sewer network has a relatively high proportion of rising mains, with previous work by Guisasola *et al.* (2009) and Guisasola *et al.* (2008) showing the potential for large variation in sewer methane concentrations at the Gold Coast. This was used to inform the default (5 mg/L) and variance (1 to 30 mg/L) estimates for this parameter, with the assumption made that all dissolved methane reaching the STP would be stripped during the treatment process.
- Data collected by Foley *et al.* (2010) was used to generate estimates for N_2O generated in the STP denitrification step. The limited available empirical data (Ahn *et al.* 2010) shows substantial variation (~1.5 orders of magnitude) in the measured N_2O emissions across different treatment plant systems, and fundamental understanding of the drivers for this variation is limited. Given the data of Foley *et al.* (2010) suggests a tendency for N_2O emission rates to be lower for plants with greater levels of nitrogen removal, a distinction was made between the assumptions for STPs with high (Elanora STP) and low (the rest) final effluent TN concentration.
- Estimates for STP emissions of NH_3, CH_4 and combustion byproducts (NO_X, SO_X, CO) were based on the modelling of similar STP treatment processes by Foley *et al.* (2010). Biogas CH_4 and CO_2 balances followed the modelling approach of de Haas *et al.* (2009).
- CO_2 emission estimates were generated from the STP carbon balance. Griffith *et al.* (2009) found that up to 25% of urban STP effluent carbon might be from non-biogenic sources in a particular catchment, although this is the only known reported dataset of this kind. In the absence of more locally relevant data, a range of 1 to 25% was used to explore the potential significance of this issue.

4.3.2.2 Solids Disposal and Cropping Offsets

All biosolids are transported by truck for agricultural reuse, with the default disposal location taken to be 200km away at the Darling Downs (as per current practice). However, a large range (60km→300km) was assumed for the uncertainty analysis to reflect the possibility that a range of disposal points might exist into the future. Inventories for the biosolids land application method were based on Foley *et al.* (2010).

It was assumed that all biosolids are applied at the rate of 1 NLBAR[3], and that the only constraint on the capacity for biosolids N to offset synthetic fertiliser use is the relative bioavailability of N in the different fertiliser sources. Following Foley *et al.* (2010), it was assumed that the bioavailability of biosolids N is typically only half that of synthetic fertiliser N.

Barry *et al.* (2006) and Pritchard *et al.* (2007) suggest that application of biosolids at 1 NLBAR is likely to substantially exceed the crop P requirements. The capacity for biosolids P to offset the application of synthetic fertiliser P was calculated based on the range of typical crop requirements (20 to 40 kg-P/ha) and biosolids loading rates (140 to 560kg-P/ha) given by Barry *et al.* (2006) and Pritchard *et al.* (2007). This implies a biosolids application rate at least 3.5 times greater than required for P fertilisation (2010), and it was therefore assumed that the biosolids would contain sufficient bioavailable P to meet the full crop requirements[4].

It was assumed that the biosolids would offset a mix of DAP (18% N; 20% P) and Urea (46% N) fertilisers. DAP offsets were calculated to reflect the crop P contribution from biosolids application. The urea offsets were calculated net of any reduced N input associated with reduced DAP usage.

[3] NLBAR = Nitrogen Limited Biosolids Application Rate, as calculated following the Queensland biosolids application guidelines (EPA 2002). These calculations estimate the mineral N availability from biosolids over a 1 year period, in order to minimise the risk of N losses from the soil.

[4] It has been found that the bioavailability of P in biosolids and synthetic fertiliser can differ greatly (e.g. O'Connor et al 2002; Pritchard et al. 2010).

Despite the high (~85%) moisture content of biosolids, it was assumed that this would have negligible impact on crop irrigation management and therefore not reduce the amount of irrigation water taken from local streams. The SEQ trial results of Barry *et al.* (2006) suggest that the use of biosolids might give increased crop yields when compared to crops fertilised with conventional products. However, no system boundary expansion was undertaken to account for the possibility of marginal crop yield increases, as further insight is required to understand whether and how these results might translate to quantitative assumptions for an LCA study. This study therefore potentially overlooks a set of benefits accruing from the agricultural reuse of biosolids.

Primary screenings waste (grit) from the STPs is trucked to the nearest landfill (10 to 50km depending on STP site). While an estimate of net greenhouse gas emissions was included in the modelling, no consideration was given to the potential for other long term impacts (such as leachate water quality impacts) associated with this disposal pathway.

4.3.2.3 Nutrient/Carbon Losses from Biosolids and Fertiliser Application

Monitoring of biosolids applications in SEQ (Barry and Bell 2006; Pu *et al*. 2008) demonstrated a significant potential for the loss of biosolids N to groundwater because of soil N accumulation below the root zone, but minimal potential for P leaching in the Darling Downs soils that were tested was found. The resultant accumulation of P in surface soils introduces a risk of future loss to waterways via surface runoff (Barry and Bell 2006). However these risks are highly dependent on soil and crop types, and will therefore be very case specific. Furthermore, converting these findings into fluxes of N and P to waterways is problematic given the uncertainties involved.

The ReCiPe model provides default delivery ratios for N and P (applied to soils) based on European conditions. In the absence of long term site specific nutrient flux modelling, these were used in this study as the defaults for biosolids nutrient losses (6% of applied N; 5% of applied P) and synthetic fertiliser nutrient losses (6.7% of applied N; 5.3% of applied P). The benefit of this approach is that it demonstrates the implications of using the default delivery ratios that are embedded inside generic LCA impact models. However it is possible that these ratios reflect higher nutrient export risks than appropriate for the soils of the Darling Downs, and this was accounted for in the uncertainty analysis. Uniform distributions for the N and P loss ratios (for both biosolids and synthetic fertilisers) were used with the maximum loss ratios set to the default ReCiPe values. To reflect the possibility of minimal surface runoff, minimal P leaching and substantial denitrification in groundwater systems, the minimum loss ratios for the uncertainty analysis were set to 0%.

Estimates for fugitive emissions arising from the land application of biosolids (N_2O, NH_3, CH_4) and fertilisers (N_2O, NH_3) were based on the ranges reported by Foley *et al.* (2010). The range for carbon sequestration (0→20%) used by Foley *et al*. (2010) was adopted for this study. It was assumed that all other biosolids carbon would mineralise to CO_2 over the long term, adopting the same non-biogenic carbon fraction as for raw sewage.

4.3.2.4 Biosolids and Fertiliser Contaminants

Statistical data on biosolids contaminant levels for the four STPs were provided by GCW, covering a range of metals and a small number of organic substances. A composite concentration profile was created from a weighted average of the mean contaminant concentration and the estimated 2007/08 dry solids production for each plant. This composite was then used as the default biosolids contaminant profile for each of the STPs. Log normal distributions were assumed for all the contaminants measured by GCW. Additional data for molybdenum was taken from Foley *et al.* (2010), as this was not included in the GC analytical data. Aluminium and Iron concentrations were calculated from the estimates of WTP sludge metals distributed to the sewer, assuming these metals report entirely to biosolids (see Section 4.3.1). While there has been recent international research interest in characterising organic micropollutants in biosolids (Hydromantis Inc 2009; Higgins 2010; WEAO 2010), no additional organics were included in the modelled biosolids assay.

Assumptions on the metals concentrations in DAP fertiliser were informed by the range of literature values summarised by Foley *et al*. (2010). Default assumptions for metals in Urea were set at 75% of the concentration limits provided by Incitec Pivot (2010).

4.3.2.5 Wastewater Disposal

GCW provided data on residual chlorine levels in the effluent from each of the four STPs, and these were assigned to both discharge pathways (marine discharge; disposal by irrigation). For metals and organics, a generic secondary effluent contaminant profile was used for all the STPs. Metal concentrations were taken from GCW data, supplemented with extra analytes detected in available data from other SEQ STPs. A hypothetical organics assay was based on contaminants detected by Watkinson *et al.* (2009), Farré Olalla (2009) and Reungoat *et al.* (2010).

The majority of Class B (secondary effluent) irrigation at the Gold Coast goes to golf courses and residential parkland. It was assumed that the default source of irrigation for these sites would be water pumped directly from local streams, and that the availability of the Class B source would increase the total irrigation volumes applied at these sites. In the absence of any supporting information to generate quantitative estimates, it was therefore assumed that the creek water offsets were only 1/3rd of the total irrigated flow. It was also assumed that no additional distributed stream extraction would be possible as the urban population grows in SEQ. The additional Class B irrigation volumes under the 'Future infrastructure mix' scenario were therefore not credited with any offset of stream water usage.

Given the low nutrient concentrations in the secondary effluent, it was assumed that only 50% of this N and P would offset fertiliser use in practice. Assuming a well-managed fertigation system is used for effluent irrigation, the risk of nutrient leaching or surface runoff was taken as negligible. Maximum possible losses under the uncertainty analysis were set at 1% of applied N or P. Estimates of N_2O emissions associated with the nitrogen content of wastewaters (discharged to waterways or by irrigation) were based on the literature data collected by Foley *et al.* (2007).

4.3.3 Centralised Infrastructure of the 'Future Infrastructure Mix'

The 'Future infrastructure mix' included three large scale infrastructure approaches to providing additional urban water supply:

- sea water desalination, based on the plant recently commissioned at the Gold Coast;
- a hypothetical indirect potable reuse (IPR) system, modelled after the infrastructure involved in the Western Corridor scheme in the Brisbane River catchment; and
- Class A+ direct reuse, based on the recently commissioned system at the Pimpama-Coomera area of the Gold Coast.

Figure 1 illustrates the location of the associated treatment plants. Table 9 provides an overview of the key characteristics for each of these three systems.

Appendix A provides the relevant assumptions and data sources for all parameters used in the infrastructure modelling. Appendix B provides a summary of the inventory flows, calculated using default assumptions for all inputs.

Table 9: Summary of treatment plant systems for 'Future infrastructure mix'.

		Seawater Desalination^	Coombabah AWTP#	Pimpama-Coomera	
				STP	AWTP
Inflow	(ML/d)	298	54.0	17.3*	17.3
Treatment system		Filtration; RO	chemical P removal; MF; RO; UV/oxidation; ROC denitrification	Compartmentalised extended aeration BNR	Mn precipitation; MF
Product water	(ML/d)	125	44.4	17.3*	17.1
- to sea	(ML/d)	--	--	0	9.9
- to AWTP	(ML/d)	--	--	17.3	--
- Class B reuse	(ML/d)	--	--	0	--
- Class A reuse	(ML/d)	--	--	--	7.2
- to water supply dams	(ML/d)	--	44.4	--	--
- to mains supply network	(ML/d)	125	--	--	--
RO reject flow to sea	(ML/d)	173	8.7	--	--
Power use from grid					
- feed	(kWh/d)	39,634	9,513	6,672	0
- treatment	(kWh/d)	432,994	51,723	17,451	4,778
- product water distribution	(kWh/d)	50,000	28,391	0	7,456
Chemical use	(kg/d)	21,282	21,360	4,486	5,363
- disinfection		sodium hypochlorite	sodium hypochlorite	sodium hypochlorite	sodium hypochlorite
biogas generation	(ML/d)	--	--	0	--
grit/sludge generation	(t-ws/d)	13.7	25	0.6	--
grit/sludge trucked to landfill	(km)	50	20	15	--
biosolids generation	(t-ds/d)	--	--	6.2	0.05^^
biosolids trucked to farms	(km)	--	--	200	200
product water - TN	(mg-N/L)	##	0.3	1.6	1.0
- TP	(mg-P/L)	##	0.02	0.3	0.2
- total chlorine	(mg/L)	##	0.0	0.5	1.2
RO reject - TN	(mg-N/L)	##	13.5	--	--
- TP	(mg-P/L)	##	0.9	--	--
- total chlorine	(mg/L)	##	0.04	--	--

^ actual performance data not available
** ADWF*
 # hypothetical AWTP
^^ chemical sludge
not modelled in the inventory analysis

4.3.3.1 Seawater Desalination

The desalination plant at the Gold Coast was going through an extended commissioning period at the time of this study, and actual operating data was not available. The predicted full supply capacity (125 ML/d) for the plant was taken from the SEQ Water Strategy (QWC 2010). Munoz *et al.* (2008), Water Corporation (2008), Vince *et al.* (2009), Mrayed et al (2009) and Leslie (2010) were used to define assumptions for operational inputs (power, fuel, chemicals, membranes) and outputs (RO concentrate, sludge), accounting for local water chemistry and trends towards improving energy efficiency. Uncertainty distributions were generated based on the variation across the sources consulted.

Product water from the Gold Coast desalination plant is pumped through a dedicated pipeline, via an intermediate booster pump station, to three different mains supply reservoirs along the pipeline route. For this study it was assumed that the product water would be evenly distributed to users along the length of the north-south delivery pipeline, and that only a portion (20%) of the product water would reach the intermediate transfer pump station. Energy use predictions for the two product water pump stations were taken from Hall *et al.* (2009). It was assumed that all supply from the reservoirs to end-users was by gravity feed. Bulk distribution losses were set equal to the assumed value (8%) for the Gold Coast mains network.

The inventory analysis did not account for any water quality characteristics of the RO concentrate stream that is discharged back to the sea. Waste sludge was assumed to be trucked to landfill, with the disposal impacts modelled as per those for STP screenings waste.

Construction estimates for the desalination plant and RO concentrate disposal pipeline were scaled up from the data of Munoz *et al*. (2008). For the product water delivery pipeline, information on the pipeline configuration (GCD 2006) was combined with the construction inventories of Grant *et al*. (2005).

4.3.3.2 Indirect Potable Reuse

The AWTP for the hypothetical Indirect Potable Reuse (IPR) system was sized at the 2007/08 capacity (54 ML/d) of the Coombabah STP, and based on the Bundamba AWTP of the Western Corridor scheme in the Brisbane River catchment.

An estimate of plant construction inventories was generated by scaling up the data provided by Munoz *et al*. (2008). The length, diameter and materials selection for the product water pipeline (from the Coombabah STP to Hinze Dam) was estimated based on information in CH2MHill (2008), with construction estimates based on the inventories of Grant *et al*. (2005). It was assumed that discharge of the RO concentrate would utilise the existing secondary effluent disposal pipeline from the Coombabah STP.

Detailed operational data was obtained for the Bundamba AWTP from WaterSecure (Robillot 2010). This included 12 month averages for inputs (energy, fuels, chemicals, membranes), outputs (sludge, wastewater flows, product water) and water quality (nutrients, chlorine) for all key streams. A simplified model was created that linked process inputs (chemicals and power use) and outputs (product water, sludge) to key influent (flow and nutrients) and output (nutrients) constraints. The model was calibrated against the actual Bundamba AWTP data. Uncertainty distributions for key model parameters were based on equivalent analysis for the Gold Coast STPs and Pimpama AWTP.

This model was then used to generate operational AWTP inventories according to the following:

- influent flow and quality parameters were set to those of the Coombabah STP secondary effluent (see Section 4.3.2);
- the nutrient and chlorine concentrations in the product water and RO concentrate would remain the same as for the Bundamba AWTP; and
- denitrification N_2O emissions were assumed to be at the lower end of the data range measured by Foley et al (2007).

WaterSecure (now Seqwater) provided statistical data on micropollutant (organic and inorganic) concentrations for the Bundamba AWTP influent and product water. This was used to calculate partitioning coefficients (the % that reaches the product water) for each contaminant. These partitioning coefficients were then applied to the Coombabah secondary effluent contaminant profile in order to estimate the micropollutant flows in the product water for the hypothetical Coombabah AWTP system. For the micropollutant fractions removed from the product water, it was assumed that all metals report to the RO concentrate. Limited data was available to estimate the contribution to organics removal by each of the RO and product water oxidation steps. Unless the WaterSecure data indicated otherwise, it was assumed that the RO membranes directed 50% of each organic chemical to the RO concentrate. No organics oxidation was allowed for in the final RO concentrate treatment stage.

A power estimate for pumping the product water to Hinze Dam was based on data collected by Hall *et al*. (2009). Losses of product water from dam evaporation or spillage were set to zero. Power use for discharging the RO concentrate was set equal to the measured data for disposal of Coombabah secondary treated effluent.

4.3.3.3 Pimpama Wastewater Treatment and Reuse

Detailed operational data (January 2009 to June 2010) was provided by GCW for the Pimpama-Coomera STP and AWTP. A STP model was created, similar to those described in Section 4.3.2, and calibrated to this empirical data.

The period covered by the data coincided with an average STP throughput of 4.6 ML/d. However the Pimpama STP-AWTP model used in the 'Future infrastructure mix' scenario was based on an average dry weather sewage inflow of 17.1 ML/d. This represents the full capacity of the existing Pimpama STP infrastructure. The following assumptions were used to scale up the Pimpama STP operations:

- chemicals usage in the model was modified to reflect recent reductions achieved through plant optimisation;
- based on previous STP analysis by the study team, the empirical power use was assumed to be 26% fixed (time-dependent), 50% load- dependent (e.g. aeration) and 24% flow-dependent; and
- effluent nutrient and chlorine concentrations were set equal to those for the empirical data.

Underpinning the Pimpama scenario for this study was the assumption that there would be no change in sewage characteristics between the 'Traditional infrastructure mix' and 'Future infrastructure mix' scenarios. To achieve this for the Pimpama STP model:

- influent sewage flow and quality (TN, TP, COD) per equivalent person (EP) were set to equal the weighted average of the four STPs included in the 'Traditional infrastructure mix' scenario. The uncertainty spreads for these parameters were set equal to those of the other four STPs; and
- the default and uncertainty distribution assumptions for mass flow of organic/inorganic micropollutants (per EP) contained in wastewater and biosolids were equal to those used for the four STPs included in the 'Traditional infrastructure mix' scenario.

The Pimpama STP model was then used to generate inventories for inflows (power, chemicals) and outflows (wastewater, solids, fugitive gases).

AWTP operations were scaled up (from the empirical data) using the following assumptions:

- the empirical power use was assumed to be predominantly (90%) flow-dependent because of the membrane treatment system and large product water distribution pumps involved. The remainder (10%) of power use was set as fixed (time-dependent);
- chemical requirements for treatment increased linearly with the increased throughput;
- effluent nutrient and chlorine concentrations were set equal to those for the 2009/10 operations; and
- AWTP sludge flows were estimated based on the modelled chemicals usage, and assumed to be mixed with the STP biosolids prior to reuse on agricultural crops (as per current practice).

GCW provided metals concentration data for the Pimpama secondary effluent and AWTP product water. This was used to calculate partitioning coefficients (the % that reaches the product water) for each metal contaminant. Taking the default secondary effluent micropollutants concentration profile that was used for the Pimpama STP model, these partitioning coefficients were then used to calculate the metals concentrations in the AWTP product water. All the removed metals were assumed to end up in the AWTP sludge. It was assumed that the AWTP achieved no organic micropollutant removal, and that all organic micropollutants therefore report to the AWTP product water.

The Class A+ product water balance was calculated as a function of the household and non-residential demand assumptions described in Section 4.2.2. Unused product water was assumed to be discharged to the sea, as per current practice. For the portion of product water that is reused in toilets and presents again to the STP, it was assumed that:

- the nitrogen content is fully nitrified and denitrified in the STP[5], increasing the amount of N_2 and N_2O produced;
- the phosphorous content is fully removed by chemical precipitation, with an associated increase in chemicals usage; and
- the organic micropollutants are fully oxidised, and the metals report entirely to the STP biosolids.

[5] This assumes that there would be no accumulation in unbiodegradable soluble compounds. Planning for the Pimpama-Coomera Class A+ scheme suggested that a small increase (<1 mg N/L) in the unbiodegradable organic N fraction would occur in the system due to water recycling via toilet flushing. To our knowledge, there have been no investigations into the extent to which this increase has materialised.

Modelling of biosolids reuse followed the assumptions described in Section 4.3.2. The non-residential reuse of Class A+ water was modelled as per the Class B irrigation described in Section 4.3.2. It was assumed that the very low nutrient concentrations in the Class A+ water meant that losses (via leaching or runoff) to waterways from household irrigation are likely to be small (1% of the irrigated N and P).

Data from Friedrich (2001) and Ecoinvent (Frischknecht *et al.* 2010) was used to estimate the construction inventories for the STP and AWTP. Detailed pipe length and materials data for the existing Class A+ reticulation network was provided by GCW, and scaled up in proportion to the number of households included in the Pimpama scenario for this study. Pipe installation inventories were based on the work of Grant *et al.* (2005). Microfiltration membrane inputs were scaled from the equivalent data for the IPR scenario.

4.3.4 Rainwater Tanks

Three rainwater tank demand scenarios were described in Section 4.1:

- tanks plumbed to external use only;
- tanks plumbed to toilet, laundry and outdoor use; and
- tanks plumbed to laundry use only.

The minimum rainwater tank volume required for new detached housing in SEQ is 5,000L. This study assumed that all rainwater tanks would be 5,000L and made of polyethylene. The materials inventories for this were based on the work of Hallmann *et al.* (2003).

Very little is known about the actual operational performance of the large number of rainwater tanks that have been installed in SEQ in recent years. Modelling of rainwater tank operations was therefore based on assumptions derived from a number of sources. The aim was to reflect the large possible range in tank operations likely to be encountered given the regulatory requirements currently in place in SEQ.

For each of the demand scenarios listed above:

- total end-use demands were set according to the assumptions described in Section 4.2;
- rainwater yields were calculated using daily timestep balances in the TANK software (Vieritz, Gardner *et al.* 2007); and
- mains water backup requirements were calculated as the difference between the two.

For the TANK modelling, the connected roof area was set to 100m^2, and default TANK assumptions were used for estimates of roof losses, first flush volume and other supply side parameters. No account was made for the possibility of climate change induced shifts in future rainfall or evapotranspiration patterns. Instead, 105 years of historical Southport (central Gold Coast) climate data was used to calculate yield probability distributions. These were then used to define uncertainty distributions on the rainwater yield for each of the demand scenarios.

A distinction was made between different systems for mains water backup. The Queensland Development Code MP 4.2 (2008) requires that all rainwater tanks on new houses use either an automated bypass switch, or route the backup water through the tank. The majority (63%) of tanks configured to supply toilet, laundry and outdoor uses were assumed to use an automated bypass switch, following survey data collected by Gardiner (2008)[6]. A large uncertainty spread was applied to this assumption to reflect the possibility for significant change in market trends over time. A portion (50%) of the 'Traditional infrastructure mix' rainwater tanks plumbed solely for external use were assumed to have mains backup water provided through a manually operated bypass. All other rainwater tanks in both scenarios were assumed to have backup water provided by tank top-up.

[6] More detail on the survey work is provided in Gardiner (2009).

At the time this analysis was undertaken, the two most popular automatic bypass switches on the market both relied on an electronic control device. Two data points for energy draw were obtained from WCG (2009) and by field measurement, and used as the extents for an uncertainty distribution on this parameter. Operation of the top-up system was assumed to be with a mechanical float valve that requires no power.

It was assumed that all tanks use an electrical pump to deliver 100% of the tank water, but that none of these use power-intensive water sterilisation (such as UV). Energy use for rainwater pumping systems can vary significantly in response to a range of factors, such as the use of pressure tanks, differences in static head and friction losses, and different types of pump controller. Publicly available data on rainwater pumping energy is very limited, and insufficient to isolate the implications of each of these different factors. Instead, this study used the best available published data to generate a single uncertainty distribution for delivery energy that incorporates these and any other possible variations.

To do this, each data point reported by Retamal *et al*. (2009) and WCG (2009) was categorised by the end uses supplied and, where the presence of an auto-switching mains bypass system was noted, adjusted for an assumed power use by this device. Seven data points were available for tanks connected to toilet, laundry and external uses, and the geometric mean of these (1.2 kWh/kL) was used as the default pumping specific energy for tanks configured to these demands. No data points were available for pumps supplying exclusively to laundry or external uses, so default power assumptions for these (0.9 kWh/kl and 0.8 kWh/kl respectively) were taken from theoretical models developed by Retamal *et al*. (2009). Given the limited data available for these three pumping configurations, the uncertainty distribution for each was based on the variability across all data points from the two studies.

4.4 Uncertainty Analysis

Modelling of the two scenarios required quantitative estimation of a large number of parameters, many of which are subject to large uncertainties. To account for this, Monte-Carlo analysis was used to ascertain the significance of these uncertainties to the final results of the study. This required the definition of uncertainty distributions for key operational parameters as described in Section 4.3 and Appendix A. Uncertainty distributions were not applied to construction inventories or background data (e.g. the inventory flows associated with power generation or materials manufacture).

In most cases, there was insufficient empirical data available to directly ascertain the distribution for any particular parameter. The following principles were used to select distribution types where this was the case:

- lognormal distributions were used where non-negative data was required, and sufficient data was available to estimate a geometric standard deviation;
- triangular distributions were used where sufficient data was not available to estimate a geometric standard deviation; or where the distributions were likely to be biased towards the upper end of the data spread; and
- Uniform distributions were used where no indication of a distribution bias was available.

Where possible, sufficient Monte-Carlo simulations were undertaken to provide a standard error of the mean less than 1% for each impact category result. However, this was not always possible due to the computational intensity of applying Monte-Carlo analysis across such a large number of uncertain parameters. Appendix D provides statistical summaries of each Monte-Carlo simulation used for this study.

It should be noted that only uncertainty associated with inventory data was accounted for quantitatively in this study. Uncertainties associated with the impact models (see Section 5.1) or normalisation data (see Section 4.6) were not included in the Monte-Carlo analysis.

4.5 Impact Models

4.5.1 LCIA Approach

The three fundamental issues that provide the focus of LCA are the protection of natural environments, protection of human health, and maintenance of natural resources. Life Cycle Impact Assessment (LCIA) is the process of converting system inventory flows into measures of potential impact in one or more of these areas.

The emission of a particular substance follows an often complex series of processes and pathways that may eventually result in some undesirable damage or degradation occurring. For example, the emission of CO_2 causes radiative forcing which results in climate change, and this is expected to eventually damage both natural ecosystems and human health. Measures of this damage are referred to as **endpoint indicators** as they directly address the ultimate concern (e.g. ecosystem protection).

However the uncertainty in modelling these pathways will usually increase the closer one gets to the endpoint. This is a challenge for the strictly quantitative LCA approach. An alternative approach is to express quantitative results in terms of some **midpoint indicator** that is at a point on the continuum (from inventory flow → endpoint damage) where the uncertainty is reduced. For the 'Global Warming' example, predicting the relative contribution of different gases (e.g. CH_4 vs. CO_2) to radiative forcing is much simpler than predicting the eventual ecosystem damage caused by climate change. The midpoint measure of radiative forcing is commonly referred to as 'Global Warming Potential'. All midpoint LCA indicators are measures of potential, rather than actual, damage.

The development of quantitative damage (endpoint) models for use in LCA lags considerably behind the development of midpoint indicator models, and LCA studies more commonly analyse midpoint indicator results for the system under consideration. Midpoint indicators were adopted for this study. The downside is that midpoint assessment increases the number, but decreases the relevance, of the quantitative measures included in a comprehensive analysis. This increases decision making complexity, and as with all multi-criteria assessment, midpoint-based LCA should be seen strictly as informing (rather than being) the decision making process.

4.5.1.1 LCIA Application

Given the number, variation and global distribution of inventory flows associated with LCA studies, practical application requires that LCIA results are calculated using linear models as described below:

	Impact Potential	=	Impact Factor	×	Inventory Flow
(*eg:*	*Global Warming Potential*	=	$GWP_{methane}$	×	*emission of methane*)

Because of the challenges involved in understanding and selecting across the large number of possible midpoint indicators in LCA, a number of **impact methods** have been developed that attempt to collate an appropriate set of indicators in order to provide a single comprehensive assessment tool. The most prominent examples include EcoIndicator99, Impact2002$^+$ and CML. These European based methods attempt in varying degrees to also provide globally relevant impact models. Outside of Europe, other impact methods have been developed with a country-specific focus, such as LIME in Japan, and TRACI in the USA. LCIA is a relatively immature field and the available impact models are constantly evolving. The ReCiPe impact method has recently been released (Goedkoop *et al.* 2009), incorporating substantial improvements in terms of both fundamental impact science and LCIA methodology.

There has been significant recent interest in developing guidelines on the application of LCIA in the Australian context. Grant *et al.* (2008) have summarised a set of LCIA impacts considered most relevant in the Australian context. They argue that the selection of impact indicators should be specific to the goal and scope of any particular LCA study. This is consistent with the principles set out in the ISO14040 and ISO14044 standards for the use of LCA (ISO 2006; ISO 2006). Also recently produced were guidelines for application of LCA specifically in the Australian building sector (Bengtsson and Howard 2010). With the objective of delivering an LCA methodology that can be

consistently applied across the building sector, the authors took a somewhat more prescriptive approach to recommendations on the selection of LCIA indicators. In both cases, the recommended indicators are almost exclusively based on foreign LCIA models. Only a very small number of LCIA models have been published based on Australian specific data or conditions.

This study aimed to choose a set of impact indicators and models that are most relevant and appropriate to the analysis of urban water systems. Because it incorporates the most recent science of the available LCIA packages, the starting point for selection of models was the ReCiPe method. A number of the chosen ReCiPe indicators were amended or replaced. In some cases this was because there have been even more recent scientific developments, while in others there remains a significant lack of consensus over the best approach.

The following sections outline the chosen set of impact categories and the adopted models. In each case, the ReCiPe 'default' is described, with important deviations noted. The full list of impact factors used for this study is provided in Appendix C.

4.5.2 Freshwater Extraction

Consideration of the impacts caused by hydrological disturbances to freshwater ecosystems is one of the least developed environmental indicators in LCIA (Koehler 2008; Canals *et al*. 2009). For this reason, the majority of urban water related LCA studies have excluded this issue from the analysis.

The ecological implications of extractions from freshwater systems depend on a range of characteristics such as the amount, rate and timing of extractions. Significant threshold effects are also considered to occur in many Australian river systems. The presence of water extraction infrastructure (such as a dam) can in itself degrade ecosystems by changing the downstream flow regime and providing barriers to the migration patterns of local species. There is no known approach to combining these complex cause-effect relationships into a single metric.

A simplified indicator (or set of indicators) is required for incorporation of this environmental issue into LCIA. Bayert *et al*. (2010) propose that three separate indicators be used to assess potential impacts on (a) resource availability in terms of competing short term human needs; (b) resource availability in terms of long term resource degradation; and (c) local ecosystems. The first is arguably a management challenge rather than a sustainability measure, while it was assumed that the second is unlikely to be relevant in the SEQ context. The third is the focus of environmental protection, and this study considers the hydrological issue solely from this perspective. The ReCiPe *Water Depletion* indicator considers the resource depletion implications of water use, and therefore is not adopted for this study.

In the absence of an available metric that can encapsulate the diversity and complexity of the impact pathways involved in ecosystem damage from hydrological change, this study adopts the most commonly used simple metric of total volumetric extraction from freshwater systems. Mila i Canals *et al*. (2009) and Pfister *et al.* (2009) both recently proposed that this should be calibrated against a measure of relative freshwater availability across different catchments, so that extractions from a highly stressed freshwater system are considered to be more significant than those from an unstressed system. This approach was not adopted for this study, as the Gold Coast study boundary involves extractions from only one major river system.

This study therefore defaults to a simple measure [ML] of total *Freshwater Extraction* (FWE) from the system under consideration. An increased FWE result implies an increased potential for degradation of the associated ecosystems. Extractions from the GC water supply dams are therefore treated the same as those from smaller GC creek systems.

The other important hydrological intervention in the Gold Coast urban water system is the interception of urban runoff by household rainwater tanks. Walsh *et al.* (2005) demonstrated that urban household rainwater capture can provide a positive ecological outcome for downstream waterways in south-east Australian conditions. This may mean that a separate midpoint indicator is required for assessing the implications of urban stormwater detention. Alternatively, a single indicator to encompass both types of intervention would need to relate both positive and negative implications. As there are no available indicators for either approach, household rainwater capture has been excluded from the FWE indicator in this study.

4.5.3 Aquatic Eutrophication Potential

4.5.3.1 Background

Most LCA studies of urban water systems consider the potential for aquatic eutrophication. The intent is to quantify the potential threat to aquatic ecosystems from nutrient enrichment, shadowing of water bodies by algal blooms, and oxygen depletion by algal breakdown (ECJRC 2010).

ReCiPe includes the most recently published version of LCIA eutrophication impact factors, using two separate indicators. The *Freshwater Eutrophication Potential* (FEP) accounts for impacts in freshwater ecosystems, and only includes impact factors for phosphorus (P) emissions. *Marine Eutrophication Potential* (MEP) accounts for impacts in marine ecosystems, and only includes impact factors for nitrogen (N) emissions. This demarcation is consistent with the commonly used assumption that P is the rate limiting nutrient for algal growth in freshwater ecosystems, and N for marine ecosystems.

ReCiPe includes impact factors for the three possible emission pathways that could lead to nutrient input to waterways: emissions directly to waterways, nutrients applied to soils that can be transferred to water bodies by leaching or surface runoff, and (in the case of N) gaseous emissions that are deposited back to land and waterways. The ReCiPe impact factors are based on European scale modelling of the fate of nutrient emissions via these three pathways.

The ReCiPe method does not follow the proposal by Karrman *et al.* (2001) that LCA eutrophication impact models should also include the potential for primary oxidation in waterways caused by emissions of organic matter and the nitrification of ammonia. This is in contrast to the Australian LCA community, which has tended to favour the inclusion of the primary oxidation effects (Grant and Peters 2008; Foley 2009; Bengtsson and Howard 2010). A recent review of LCA impact modelling (ECJRC 2010) argues that inclusion of this primary oxidation pathway is not consistent with the use of midpoint Eutrophication indicators, as it does not account for two of the possible environmental impacts associated with nutrients discharge.

4.5.3.2 Approach Adopted for this Study

The ReCiPe eutrophication impact models were not directly used for this study. Instead, the choice of indicator for aquatic eutrophication was guided by the following two objectives:

- to provide generalist results that are broadly informative across the range of different wastewater system configurations in SEQ; and
- given this, to consider the potential contribution from the full suite of possible substances and emission pathways.

To achieve this, the impact model used for this study was defined as follows:

1. Given that wastewaters and biosolids are discharged to both coastal and freshwater catchments across SEQ, a single *Aquatic Eutrophication Potential* (AEP) indicator was used.
2. The model assumes that both N and P emissions can cause eutrophication impacts in all waterways included in the study. The rationale for this choice was that:
   - all effluent discharges (the major source of nutrient emissions in this study) in the GC area are to estuarine environments or coastal catchments. Abal *et al.* (2005) have suggested that emissions of both N and P can drive eutrophication in coastal receiving waters of SEQ; and
   - while this analysis assumes that all biosolids nutrients are being applied to inland freshwater catchments that may well be phosphorus limited, biosolids reuse might also occur in coastal agricultural lands at the GC and elsewhere in SEQ.
3. The primary oxidation pathway was included, so as to assess whether this issue might be significant to the results of this study.

The AEP results are expressed as a mass of equivalent phosphate emissions [kg-PO4-*e*]. Consistent with the ReCiPe and other LCIA impact methodologies for aquatic eutrophication, the AEP impact factor [kg-PO4-*e*/kg-emission] for the emission of each substance to each receiving environment is a combination of the relevant fate factor (FF) and effect factor (EF). These factors are described in more detail by the equation below:

$$IF_{S,E} = FF_{S,E} \times EF_S$$

where: $IF_{S,E}$ is the Impact Factor [kg-PO4-*e*/kg-emission] for the emission of substance (S) to receiving environment (E)

$FF_{S,E}$ is the fraction [w/w] of substance (S) emitted to receiving environment (E) that reaches a waterway

EF_S is the relative potential [kg-PO4-*e*/kg-emission] for substance (S) to cause impacts on reaching a waterway

The fate, effect and impact factors for each substance are summarised in Table 10. The effect factors are based on the Redfield Ratio (Redfield *et al*. 1993) which describes the stoichiometric ratio of C:N:P in 'typical' aquatic phytoplankton. For ammonia, ammonium and COD, the effect factors were adjusted to also account for primary oxidation in line with the recommendations of Karrman *et al.* (2001).

Table 10: Summary of AEP Impact Factors.

substance (S)	Effect Factor (EF_S)	Fate Factors ($FF_{S,R}$)			Impact Factors ($IF_{S,R}$)		
		Air	Soil	Water	Air	Soil	Water
Nitrogen oxides (NO_X)	0.129	0.090	--	--	0.012	--	--
Ammonia (NH_3)	0.432	0.078	--	--	0.034	--	--
Ammonium (NH_4^+)	0.409	--	0.078	1	--	0.032	0.409
other Nitrogen (N)	0.424	--	0.067	1	--	0.028	0.424
Phosphate (PO_4^{3-})	1.000	--	0.053	1	--	0.053	1.000
other Phosphorus (P)	3.060	--	0.053	1	--	0.162	3.060
COD	0.022	--	--	1	--	--	0.022

Fate factors for emissions to all (marine and fresh) waterways were set to 1. Fate factors for airborne N emissions were taken from the European-based values used in ReCiPe, as no such data for Australian systems has been collated for use in LCA. The ReCiPe fate factors for terrestrial nutrient discharges were used for 2nd order inventories (e.g. any nutrient disposal related to the supply of materials or power). However for 1st order inventories (the nutrient loadings to soil from the reuse of Gold Coast biosolids and effluent), estimates of gaseous losses and nutrient fluxes to waterways were done at the inventory stage (see Section 4.3.2).

4.5.4 Toxicity Potential

4.5.4.1 Background

Toxicity impact categories are frequently included in LCIA studies, with a number finding that urban water system operations make substantial contributions to LCIA toxicity results. The extent of public and research interest (in SEQ) in the toxicity implications of water recovery from wastewater also provides an incentive to include toxicity analysis in this study.

The toxicity impact factors used in LCIA are generated using standalone toxicity models designed specifically for this purpose. Interpretation and comparison of LCA toxicity results across studies has, in the past, been complicated by the use of competing toxicity models (Hauschild *et al*. 2008). Impact 2002 (underpinning the Impact2002+ LCIA method) and USES-LCA_v1 (underpinning the CML LCIA method) were two prominent European toxicity models that underpinned much of the urban water related LCA in recent times. Recent attempts to explore and minimise the differences between different LCA toxicity models has produced a new, consensus-driven LCA model named USETox

(Rosenbaum *et al*. 2008). In parallel, the USES-LCA_v2 model has incorporated substantial improvements that have been reported in the literature (van Zelm *et al*. 2009).

Each of these four toxicity models has the following characteristics in common:

- They involve models for human toxicity, and all or some of marine, freshwater and terrestrial ecotoxicity.
- Midpoint impact factors (IF) can be derived and expressed as a total equivalent mass emission for the reference substance [kg-reference substance]. These would account for fate, exposure and toxicity aspects of a chemical emission according to the following formulae structure:

  $IF_{S,C,E} = FF_{S,C,Z} \times EF_{S,E} \times TF_{S,Z,R}$

  where: $IF_{S,E}$ is the Impact Factor [kg-reference substance/kg-emission] for the emission of substance (S) to compartment (C) that affects system (Z), where Z is either environment (E) or the human population

  $FF_{S,C,E}$ is the concentration response in environment (E) to a mass emission of substance (S) into compartment (C)

  $EF_{S,E}$ is the exposure (w/w fraction) of ecosystems or humans to the concentration response in environment (E) to a mass emission of substance (S) into compartment (C).

  $TF_{S,Z,R}$ is the toxicity to ecosystems/humans from exposure to substance (S), relative to the toxicity of some reference substance (R)
- The fate, exposure and ecotoxicity factors are calculated using continental scale or globalised average assumptions so as to maintain relevance over a global spectrum of emission locations.

Interpretation of LCA toxicity results should be mindful of a number of important considerations. Firstly, LCA toxicity models provide a best estimate measure of potential impacts, rather than the worst-case basis of toxicity risk assessment (Larsen and Hauschild 2007). The available models also have a number of limitations that are described below:

- They are dependent on global assumptions rather than focussing on analysis relevant to some specific local area.
- They are linear and additive (across chemicals), meaning that the quality of the results is highly dependent on the availability and choice of chemicals used in the inventory data, and the availability of relevant chemical toxicity impact factors. Even the most comprehensive LCA toxicity models cover only a small portion of the known chemical pollutants that might be encountered at some part of the global system.
- A consensus is emerging that they may significantly overstate the implications of metals emissions to waterways (Ligthart *et al*. 2004).

4.5.4.2 Implementation of LCA Toxicity Models

Because of the underlying complexity and the thousands of impact factors involved, LCA users typically adopt unchanged the impact factors that are produced by these toxicity models.

USES-LCA_v2 uses *Marine Ecotoxicity Potential* (MEP), *Freshwater Ecotoxicity Potential* (FEP), *Terrestrial Ecotoxicity Potential* (TEP) and *Human Toxicity Potential* (HTP) impact categories. Impact factors [kg-1,4DCB-*e*/kg-emission] are provided for ~3,000 substances, relative to the reference substance 1,4-dichlorobenzene. The results for each of the four impact categories are therefore expressed in terms of a total equivalent mass emission of 1-4 dichlorobenzene [kg-1,4DCB-*e*]. Despite the apparently consistent units, the results cannot be directly compared across the impact categories. A MEP result of 30 kg-1,4DCB-*e* does not represent the same potential for ecosystem damage as a TEP result of 30 kg-1,4DCB-*e*.

ReCiPe adopts the four toxicity indicators (MEP, FEP, TEP and HTP) of USES-LCA_v2, but provides impact factors for only a subset of the substances and emission compartments covered by the source model. 1-4-dichlorobenzene is used as the reference substance for each of the four impact categories. ReCiPe provides two alternative sets of impact factors for each of the toxicity impact categories. The

'Individualist' version of impact factors is the least conservative, based on relatively short (100yr) timeframes, and excluding those substance/exposure route combinations that are considered the most uncertain. The 'Heirarchist/Egalitarian' version is more conservative, and will generally provide the greatest toxicity results of the two choices.

Lundie *et al*. (2007) provided the only published version of an Australianised LCA toxicity model, modifying the fate and exposure factors in USES-LCA_v1 to account for the distinct geographical differences between Australia and Europe. They found this to make a significant difference to the toxicity results that are generated. Unfortunately, toxicity impact factors were generated for only a small number of the organic micropollutants that were included in the wastewater inventories for this study.

4.5.4.3 Approach Adopted for this Study

Because of the two limitations described above, the Australianised LCA toxicity model (Lundie *et al*. 2007) was not adopted for this study. The USETox model (Rosenbaum *et al*. 2008) was also not used as impact factors were only available for freshwater and human toxicity. Instead, the MEP, FEP, TEP and HTP impact categories of ReCiPe were used.

To compensate for the risk of overstating the metals toxicity implications, the 'Individualist' version of the ReCiPe models were adopted as these provide the least conservative (lowest) toxicity impact factors for metals emissions to the environment.

4.5.4.4 Limitations of the Adopted Toxicity Models

The following lists a number of limitations with the adopted toxicity models that should be recognised if the results of this study are to be appropriately interpreted:

- Impact factors were available for only 19 of the ~80 organic micropollutants included in the generic secondary effluent assay described in Section 4.3.2.
- No individual impact factors were modified to reflect particular local conditions.
- The models do not account for the geographic differences that distinguish Australia from the majority of the developed world.
- Following the recommendations of Ligthart *et al*. (2004), the adopted MEP model assigns zero impact to certain essential metals in which oceans are typically deficient. No consideration has been given to whether or not this is relevant for the inshore waters of Moreton Bay.
- While the inventory data includes the recycling of pollutant chemicals to the Gold Coast dams as part of the Indirect Potable Reuse system (see Section 4.3.3), the toxicity impact factors are based on the assumption that only a small portion of global freshwater stocks are used for urban water supplies. In contrast, the dam in question is used predominantly for mains water supply. The adopted HTP model will therefore substantially underestimate the level of human exposure to any chemicals recycled by the IPR system.
- Section 4.3.1 highlights that the toxicity implications of chemical water quality in household supplies from dams or rainwater tanks are excluded from this study.

4.5.5 Global Warming Potential

Global Warming Potential (GWP) is a commonly used impact category in LCA of urban water systems, and now a relatively high profile water industry concern. GWP is included in all available broad-spectrum LCIA methods, with the midpoint indicator typically reported as the total mass of CO_2 emissions [kg-CO_2-*e*]. ReCiPe follows this approach, with the relative impact factors [kg-CO_2-*e*/kg-emission] for different gases based on the most recent 100 year equivalency ratios published by the IPCC (2007).

This set of emission factors differs from those required for use under Australian Greenhouse Office (AGO) reporting requirements, which were adopted for the purpose of meeting Australia's requirements under the Kyoto Protocol. While it will introduce discrepancies between the GWP results of this study and reporting or audit driven studies of the equivalent system, this study uses the

ReCiPe GWP indicator and impact factors which represent the latest available science on the relative importance of different gaseous species.

The only modification was the inclusion of an impact factor for ammonia emissions (3.9 kg-CO_2-*e*/kg-NH_3) following the Foley *et al.* (2010) assumption that 1% of volatilised ammonia nitrogen would eventually be returned to terrestrial or marine ecosystems and oxidised to N_2O.

4.5.6 Ozone Depletion Potential

ReCiPe provides a midpoint indicator for assessing the potential depletion of the ozone layer due to the emission of a range of substances. The *Ozone Depletion Potential* (ODP) of each substance [kg-CFC11-*e*/kg-emission] is expressed relative to that for CFC-11 (Trichlorofluoromethane). The default ReCiPe impact factors for ODP reflect the most recent steady-state values published by the World Meteorological Organisation (WMO 1999), and include the CFCs, HCFCs and other chlorinated or brominated compounds addressed by the Montreal Protocol on Substances that Deplete the Ozone Layer.

Because the worst of these substances have largely been eliminated from use in developed countries, ozone depleting substances would not normally be expected to feature as an issue of concern for the management of Australian urban water systems. However, Ravishankara *et al* .(2009) and Daniel *et al.* (2010) have recently argued that attention should also be focussed on the risks to the ozone layer associated with Nitrous Oxide (N_2O) emissions. They argue that N_2O mitigation represents the biggest opportunity for facilitating ozone layer recovery into the future. This is highly relevant to the urban water sector, as awareness is growing that wastewater treatment systems might be a substantial source of N_2O emissions (Ahn *et al.* 2010; Foley *et al.* 2010).

ODP was therefore included in this analysis, with the results expressed as a total mass of CFC-11 equivalents [kg-CFC11-*e*]. The ReCiPe ODP indicator and default impact factors were adopted, supplemented with the ODP factor proposed for N_2O (0.017 kg-CFC11-*e*/kg-N_2O) by Ravishankara *et al.* (2009). This is similar in magnitude to the ODP factor for many of the HCFCs being phased out under the Montreal Protocol (and included in the ReCiPe ODP indicator). While Plummer *et al.* (2010) and Daniel *et al.* (2010) have cautioned that the future ozone depleting potential of N_2O will be suppressed by climate change, there does not appear to be any contention that N_2O will cause ozone layer depletion to some degree[7]. In the absence of any quantitative alternatives, the Ravishankara *et al.* (2009) factor for N_2O has therefore been adopted so as to explore the potential relevance of ozone depletion to this analysis.

The arguments by Plummer *et al.* (2010), Daniel *et al.* (2010) and Eyring *et al.* (2010) that CO_2 and CH_4 emissions are likely to cause a long term reduction in ozone layer depletion (i.e. have a beneficial effect), raise the prospect that negative ODP characterisation factors might also be included for these substances in LCIA. However no such factors for these substances were found in the literature, and they were therefore excluded from the ODP calculations in this analysis.

4.5.7 Resource Depletion

The depletion of fossil and non-fossil geological reserves is another issue common to most urban water system LCA studies, and to all broad-spectrum LCIA methods. While this suggests a strong consensus that LCA provides a suitable forum for considering the sustainability implications of resource depletion, there is no such consensus on how best to characterise the impacts of marginal changes to abiotic resource use (Bauman and Tillman 2004; Finnveden *et al.* 2009; Goedkoop *et al.* 2009).

ReCiPe accounts for resource depletion by considering the marginal cost increases that would be incurred by an increase in resource extraction, and explicitly rejects the alternative concepts (resource availability; rate of resource depletion; environmental impacts of future resource extraction; system exergy) that have been prominent in the LCIA literature prior to the development of the ReCiPe model. Midpoint level consideration of resource depletion in ReCiPe is split into separate indicators

[7] Chipperfield (2009) notes that the ozone-depleting capacity of N2O has been recognised in the literature since the 1970s, but that this has not translated into public awareness nor policy responses.

for *Fossil Fuel Depletion* (FFD) and *Minerals Depletion* (MD). This study has accepted the ReCiPe approach on the grounds that it is the most recent model available, without critiquing the merits of the alternatives.

The ReCiPe FFD indicator was adopted unchanged for this study, with the results expressed as a total equivalent mass of oil [kg-oil-*e*] extracted from the ground. The impact factors for each fossil stock [kg-oil-e/kg-material] are based on the relative energy content of the different fuels. The ReCiPe MD indicator was not used in this study. The rationale for this choice is discussed further in Section 4.5.8.

4.5.8 Impact Categories Not Used

The selection (described above) of impact categories for use in this study represents only a subset of those available in the LCA literature, and there are many other impact categories that have been used in previous LCA studies of urban water systems. As an example, the following lists those ReCiPe midpoint impact categories that were not considered for inclusion in this study:

- terrestrial acidification;
- emissions of particulate matter;
- photochemical oxidation formation (smog);
- radiation; and
- land use.

Following the principles recommended by Grant *et al.* (2008), these issues were excluded on the expectation that the urban water system impacts would be relatively insubstantial. This assumption was not tested during this study.

4.5.8.1 Minerals Depletion

As discussed in Section 4.5.7, the issue of mineral resource depletion was excluded from this study. This is recognised as a shortcoming for two reasons. Firstly, urban water systems involve substantial amounts of physical infrastructure, and both the infrastructure intensity and type of materials use would be expected to vary greatly as alternative water supply options are adopted. Secondly, urban wastewater systems play a particularly significant role in Australian and global phosphorus balances (Tangsubkul *et al.* 2005; Cordell *et al.* 2009; Cordell and White 2010). Phosphorus is a non-substitutable nutrient required for food production. Expectations are that phosphorus demand will increase dramatically into the future, as global food crop demand increases with population growth and shifts in diet in developing countries (Cordell *et al.* 2009). The importance of phosphorus depletion is an emerging issue, with recent projections by Cordell *et al.* (2009) suggesting that global phosphorus supplies may peak at some time in the next 30-60 years.

While there is one known example of a LCIA resource depletion indicator that accounts for phosphorus reserves (Guinée *et al.* 2002), it uses data that is likely to be outdated and a metric that was specifically rejected during the development of the ReCiPe minerals depletion indicator. While Goedkoop *et al* (2009) provide background data on phosphorus reserves, phosphorus depletion was not included in the final ReCiPe MD model. Given the ongoing debate about long term forecasting of phosphorus supply availability and price (GPRI 2010; Van Kauwenbergh 2010), it may be that further methodological development is required before phosphorus depletion can be included in LCIA resource depletion indicators. In the absence of this capacity, it was decided to exclude the MD indicator for this study.

4.5.8.2 Salinity

Soil salinisation is a high-profile concern in irrigated agricultural areas of Australia. In response to this, Feitz *et al.* (2002) produced an LCIA impact category that could account for potential soil salinisation effects of irrigation. The limited application of this indicator in the literature (Feitz and Lundie 2002; Munoz *et al.* 2010) has been specifically for agricultural based LCA. Wastewater irrigation in the Gold Coast area is predominantly for urban spaces rather than farmland. This study did not consider the possibility of urban landscape degradation due to the salinity of the treated wastewater being applied, and the soil salinisation LCIA indicator was therefore not adopted.

4.6 Australian Normalisation Data

Analysis across such a large number of impact categories introduces challenges for decision makers. Since urban water planners are unlikely to have experience in incorporating some of these issues into the decision making process, it is likely that additional perspectives will be required to help them prioritise across the impact categories.

The most common response is to adopt the normalisation step typical in multi-criteria assessment (MCA), whereby the results for each category are divided by some appropriate benchmark that is expressed in the same units as the raw result. The normalised result therefore indicates the contribution made towards the benchmark value.

There is a range of benchmarking approaches used in more general applications of MCA, however only a limited set of approaches used in the LCA literature. The most common of these is to normalise against estimates of total impact associated with economic activity. The global scope of LCA results means that the most strictly appropriate choice of benchmark is arguably the global economy (Huijbregts *et al*. 2003). For any particular case study, the perspective provided by such a normalisation step would therefore be the percentage contribution made towards this overall impact.

However because institutional and social priorities tend to be framed more from a national rather than global perspective, a global benchmarking step can lack relevance for decision makers. LCA results are therefore often normalised against estimates of total impact associated with national economies. The most common approach to generating national LCA normalisation datasets is to base them on national production inventories. Publicly available Australian normalisation datasets for LCA (Lundie *et al*. 2007; Foley and Lant 2009; Grant 2010) use this approach.

While this ascribes responsibility to Australia for the environmental burdens associated with the production of the large amount of goods and services exported overseas, it doesn't account for environmental burdens associated with the generation of goods and services that are imported. It has been argued that regional normalisation datasets should be consumption based so as to overcome this problem (Breedveld *et al*. 1999; Sleeswijk *et al*. 2008), and the use of input/output analysis might provide a means for doing this. However limitations in data availability mean that this has not commonly been done.

The use of normalisation data based on Australian production inventories was the only approach possible within the scope of this project. The chosen Australian inventory was predominantly based on the mining, greenhouse gas emissions and National Pollutant Inventory data compiled by Foley *et al.* (2009), supplemented with the pesticide usage data presented by Lundie *et al*. (2007). The normalisation data for the Freshwater Extraction impact category was based on an estimate of total Australian use from surface and groundwater systems (National Water Commission 2007).

This dataset was used to calculate a set of Australian impact potentials by applying the impact models chosen for use in this study. These Australian impact potential results were used for the normalisation step described in Chapter 5.

It should be recognised that both Lundie *et al*. (2007) and Foley *et al*. (2009) identified the potential significance of major gaps in this normalisation dataset. There may be large differences in quality of the Australian reference values across the different impact categories, and this can bias the interpretation of normalised case study results (Heijungs *et al*. 2007). It should also be noted that the statistical uncertainty analysis described in Section 4.4 does not include consideration of data uncertainty for the Australian normalisation dataset.

5. KEY SOURCES OF IMPACT ACROSS THE WATER CYCLE

The goal of this chapter is to investigate the range of environmental impacts associated with the water supply and wastewater system, and to identify the main contributing factors in each case. The results and discussion are presented in three stages:

- For each of the two infrastructure scenarios, the results for each impact category are broken down to identify the main causative factors.
- The scale of the overall results are compared across the two scenarios, and benchmarked against the Australian economy in order to understand the relative significance of the different impact categories.
- The benchmarked results are then broken down to identify which key parameters might be making the biggest contribution to the overall Australian environmental burden.

The first step directly provides the greenhouse gas profile required for Research Objective 1.

Research Objective 2 is addressed by the second step (providing perspective on the scale and significance of the environmental issues under consideration) and the first step (identifying the source of each of the impacts). The third step contributes to Research Objective 2 by adding additional perspective on the opportunities to mitigate the environmental burden of the urban water system.

Collectively, these three steps identify important data gaps and provide perspective on how they influence analysis of the overall urban water system. This provides information relevant to Research Objective 5.

The analysis of this chapter is based directly on the two scenarios described in Section 4.1 and 4.2. The functional unit is therefore described as:

> *The provision of water supply and wastewater services, for 1 year, to an urban and peri-urban population for the Gold Coast region of SEQ.*

5.1 Breakdown of the Results

The results for this first step were modelled using the default assumptions for each parameter as described in Section 4.3. This allowed an interrogation of the contributions made by different elements of the systems under consideration.

Figure 4 and Figure 5 show how the results for the 'Traditional infrastructure mix' and 'Future infrastructure mix' in each impact category are broken down across the different components of the urban water system. These confirm that system operations are responsible for the majority of the impacts, with the construction phase making only a minor contribution in all impact categories other than for *Human Toxicity Potential*. For both scenarios, wastewater management (sewerage, treatment and disposal) makes the biggest overall contribution across the range of impacts considered. Nevertheless, the contributions of water supply (recycling, mains supply and rainwater tanks) do increase substantially for the 'Future infrastructure mix'.

5.1.1 Freshwater Extraction

Figure 4 and Figure 5 suggest that water 'embedded' in power supply and other material inputs is not significant in the context of urban water management, contributing less than 1% to the total Freshwater Extraction (FWE) result. The FWE offset ascribed to the Class B (secondary effluent) reuse is relatively small as a result of our assumptions about the impact of this on irrigator behaviour.

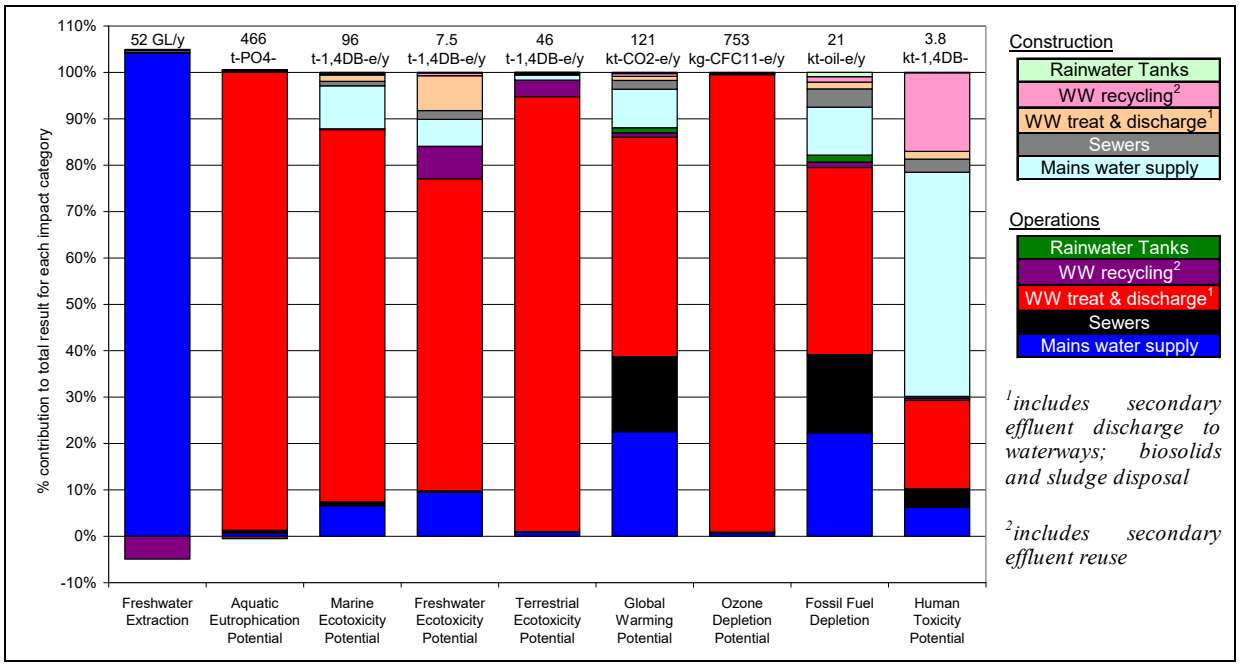

Figure 4: Breakdown of the impacts for the 'Traditional infrastructure mix'.

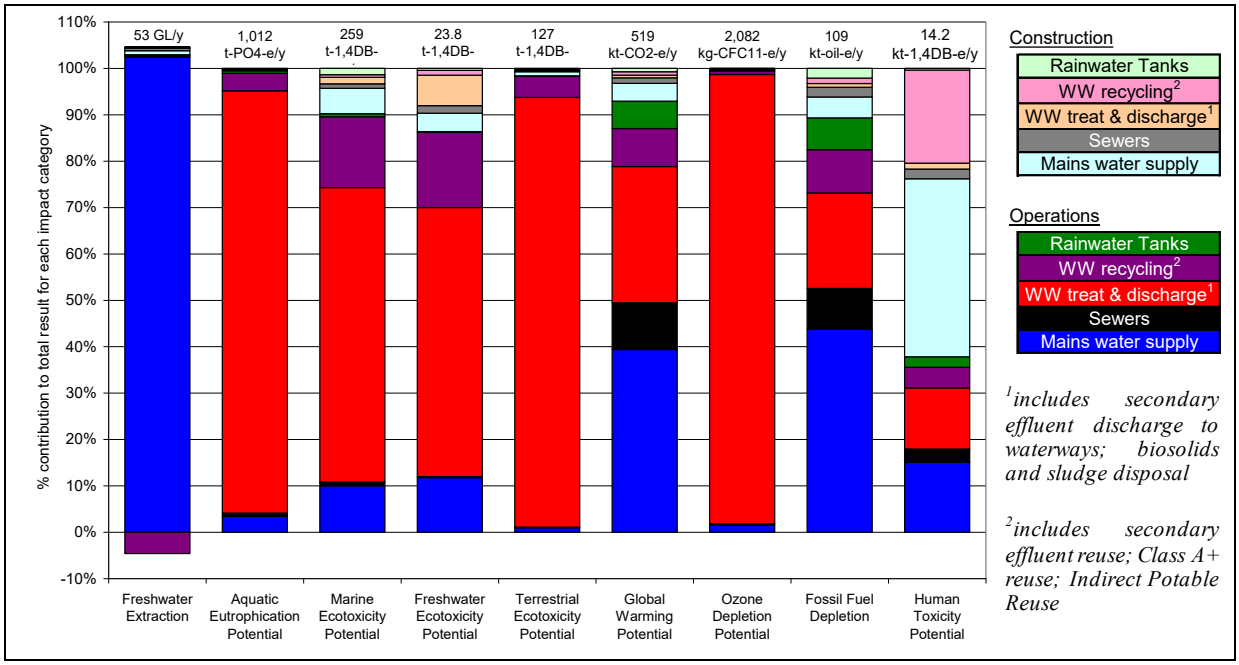

Figure 5: Breakdown of the impacts for the 'Future infrastructure mix'.

5.1.2 Global Warming Potential and Fossil Fuel Depletion

Table 11 provides a detailed breakdown of the results for *Global Warming Potential* (GWP) and *Fossil Fuel Depletion* (FFD), showing that power use dominates in both of these categories. The substantial increase in power use contribution for the 'Future infrastructure mix' reflects the more energy intensive water supply infrastructure that it entails. From a comparison across Figure 4 and Figure 5, the big increases in power use are associated with:

- Mains Water Supply operations (because of energy-intensive sea water desalination);
- Rainwater Tank operations (because of the substantial growth in tank numbers); and
- Recycling operations (because of the membrane based advanced treatment, and extra pumping requirements).

Despite the increased power intensity of the water supply mix, Figure 5 shows that the centralised wastewater collection and treatment steps still account for ~40% of the total GWP in the 'Future infrastructure mix'. This is because of the significant contribution from the fugitive nitrous oxide (N_2O), methane (CH_4) and non-biogenic carbon dioxide (CO_2) emissions associated with wastewater collection and treatment. The most significant sources of these fugitive emissions were N_2O from STP nitrification-denitrification processes (6% of total GWP for the 'Future infrastructure mix'), and dissolved CH_4 generated in sewers (3%). Estimating these flows is subject to considerable uncertainty, with increasing research effort being directed into tracing their origins and providing more substantial quantitative data (Guisasola *et al*. 2008; de Haas *et al*. 2009; Guisasola *et al*. 2009; Ahn *et al.* 2010; Foley *et al*. 2010).

There is also a significant contribution (4%) from the fugitive CH_4, NH_3 and particularly N_2O gases released from the biosolids. The N_2O and NH_3 emissions that are avoided by reducing fertiliser use are much smaller in comparison. The emission factors used to generate these results, and the possible level of carbon sequestration from biosolids reuse, are all sources of uncertainty requiring further investigation.

Table 11: Key contributors to the Global Warming Potential and Fossil Fuel Depletion results.

	Global Warming Potential (kt-CO2-e/y)		**Fossil Fuel Depletion** (kt-oil-e/y)	
	Traditional infrastructure mix	**Future infrastructure mix**	**Traditional infrastructure mix**	**Future infrastructure mix**
Total	**121 (100%)**	**519 (100%)**	**21 (100%)**	**109 (100%)**
Power use	63 (52%)	374 (72%)	15 (73%)	91 (84%)
	sewer 12%	sewer 8%	sewer 17%	sewer 9%
	STP treatment 21%	STP treatment 14%	STP treatment 29%	STP treatment 16%
	effluent discharge 6%	effluent discharge 3%	effluent discharge 8%	effluent discharge 3%
	WW reuse 1%	WW reuse 7%	WW reuse 2%	WW reuse 8%
	mains supply 11%	mains supply 35%	mains supply 15%	mains supply 41%
	rain tanks 1%	rain tanks 6%	rain tanks 2%	rain tanks 7%
Fugitives (WWT & WW disch)	18 (15%)	48 (9%)		
	CO_2 1%	CO_2 1%		
	N_2O 9%	N_2O 6%		
	CH_4 (sewer) 4%	CH_4 (sewer) 3%		
Fugitives (dams)	8 (7%)	10 (2%)		
	CH_4 7%	CH_4 2%		
Chemicals use	8 (7%)	24 (5%)	2 (9%)	5 (5%)
	manufacture 5%	manufacture 4%	manufacture 8%	manufacture 4%
	transport 1%	transport 1%	transport 1%	transport 1%
Biosolids & WW --> land	11 (10%)	32 (6%)	1 (3%)	2 (2%)
	fugitives 5%	fugitives 4%		
	transport 4%	transport 3%	transport 3%	transport 2%
offset Fertiliser use	-3 (-3%)	-9 (-2%)	-1 (-3%)	-2 (-1%)
	supply -1%	supply -1%	supply -3%	supply -1%
	field fugitives -2%	field fugitives -1%		
Construction	14 (12%)	37 (7%)	4 (18%)	12 (11%)
	networks 7%	networks 4%	networks 12%	networks 7%
	tanks <1%	tanks 1%	tanks 1%	tanks 2%
	other 5%	other 2%	other 4%	other 2%
Other	1 (1%)	4 (1%)	0 (<-1%)	0 (<1%)

N_2O emissions from wastewater discharge points (<1%) were far less significant to the GWP results, because of the low final effluent nitrogen mass loads. CH_4 generation from the secondary treatment process was also only minor (<1%) as only a small portion of the Gold Coast sewage is processed with anaerobic treatment. Estimated CO_2 from the breakdown of non-biogenic organic compounds (e.g. detergent stocks of fossil fuel origin) made a 2% contribution to the total GWP, predominantly released at the STPs and biosolids disposal points. The potential for sewage carbon to have a substantial non-biogenic component is only a recent finding, and there is not yet any Australian data available to support such estimates.

The contribution from dam-sourced fugitive CH_4 emissions (7%) is also notable for the 'Traditional infrastructure mix', although relatively less for the 'Future infrastructure mix' since it involved no additional dams. The significance of this contribution should not be overlooked, given the very large uncertainty involved and potential for emission levels to be much greater than used for this analysis (Hall *et al*. 2009).

Chemicals use makes a small but notable contribution to both the GWP (5-7%) and FFD (5-9%) results under both scenarios, the main culprits being the flocculation steps for mains water treatment (using aluminium sulphate plus lime for pH adjustment) and advanced wastewater treatment (using ferric chloride plus lime for pH adjustment). Chemicals manufacturing was the main source of these impacts, with the role of chemicals transport being a lesser concern (~1% of total GWP and FFD under both scenarios).

Despite the nearly 7,000km of water supply, sewerage and water recycling pipelines currently in place at the Gold Coast, the GWP and FFD 'embedded' in construction materials is relatively small compared to that associated with the system operations. This does not change for the 'Future infrastructure mix', even with the proliferation of rainwater tanks and the additional pipelines required for extra recycling schemes.

5.1.3 Ozone Depletion Potential

Table 12 illustrates that fugitive N_2O emissions from wastewater management are the dominant source of *Ozone Depletion Potential* (ODP) for both scenarios. While N_2O was assigned only a relatively small ODP factor, this result is driven by the magnitude of the N_2O emissions when compared to the higher-profile ozone depleting substances (such as CFCs) that have largely been eliminated from use in Australia. Even with the most conservative assumptions for N_2O generation, it would still be the dominant source of ODP in this case study.

5.1.4 Aquatic Eutrophication Potential

The *Aquatic Eutrophication Potential* (AEP) impacts of both scenarios are dominated by the nutrient load in direct wastewater discharges to receiving waters. Figure 4 and Figure 5 show a partial but significant shift in the pathways, from the secondary treated effluent (of the 'Traditional infrastructure mix') to the AWTP discharges of the 'Future infrastructure mix'.

Table 13 also shows significant indirect pathways that contribute to the AEP results. Our assumptions for leaching and runoff losses from biosolids (applied to agricultural soils) resulted in substantial AEP burdens from this source for both the 'Traditional infrastructure mix' (+18%) and 'Future infrastructure mix' (+23%). These are only partially offset by the assumed losses that would have resulted from the displaced fertiliser use. This is because we assumed biosolids nutrients to be less bioavailable than those in synthetic fertilisers, and therefore a higher nutrient loading would be required (for a given crop area) when using biosolids. Furthermore, the application of biosolids based on nitrogen crop demands is likely to mean significant over-fertilisation with phosphorus (Barry and Bell 2006; Pritchard *et al*. 2007). No consideration was given to the possibility that fertiliser application in subsequent years (following the biosolids disposal to a particular site) would change to compensate for this. The assumptions on fertiliser offsets and the ratio of losses (to waterways) from the different nutrient sources are parameters subject to large uncertainty. While the same applies to estimating the net nutrient balance for effluent reuse, the implications were relatively minor because the nutrient loadings to land from effluent irrigation were far smaller than those from biosolids disposal to agriculture.

Gaseous nitrogen emissions (NH_3 from biosolids, and NO_X from power generation) transferred from the airshed to waterways also make a notable contribution to total AEP, particularly for the 'Future infrastructure mix' (9%) with its increased energy intensity for water supply. The relevance of these results is uncertain, given they are based on European (and not Australian) fate models.

Table 12: Key contributors to the Ozone Depletion Potential results.

	Ozone Depletion Potential (kg-CFC11-e/y)			
	Traditional infrastructure mix		Future infrastructure mix	
Total	**753**	**(100%)**	**2,082**	**(100%)**
Power use	10	(1%)	57	(3%)
Fugitives (WWT & WW disch)	631	(84%)	1,710	(82%)
	CO_2	0%	CO_2	0%
	N_2O	84%	N_2O	82%
	CH_4 (sewer)	0%	CH_4 (sewer)	0%
Fugitives (dams)	0	(0%)	0	(0%)
	CH_4	0%	CH_4	0%
Chemicals	3	(<1%)	7	(<1%)
Biosolids & WW --> land	216	(29%)	601	(29%)
	fugitives	28%	fugitives	29%
	transport	<1%	transport	<1%
offset Fertiliser use	-108	(-14%)	-301	(-14%)
	supply	<-1%	supply	<-1%
	field fugitives	-14%	field fugitives	-14%
Construction	2	(<1%)	5	(<1%)
Other	1	(<1%)	3	(<1%)

Table 13: Key contributors to the Aquatic Eutrophication Potential results.

	Aquatic Eutrophication Potential (t-PO4-e/y)			
	Traditional infrastructure mix		Future infrastructure mix	
Total	**466**	**(100%)**	**1,012**	**(100%)**
WW --> sea	381	(82%)	736	(73%)
WW --> dam	0	(0%)	4	(<1%)
WW --> land	0	(<1%)	0	(<1%)
	leaching/runoff	0%	leaching/runoff	0%
	NH_3 fugitives	<1%	NH_3 fugitives	<1%
Biosolids --> land	93	(20%)	257	(25%)
	leaching/runoff	18%	leaching/runoff	23%
	NH_3 fugitives	2%	NH_3 fugitives	2%
	transport	2%	transport	<1%
offset Fertiliser use	-23	(-5%)	-61	(-6%)
	leaching/runoff	-4%	leaching/runoff	-5%
	NH_3 fugitives	<-1%	NH_3 fugitives	-1%
	supply	<-1%	supply	<-1%
Power use	11	(2%)	66	(7%)
	airborne NO_X	2%	airborne NO_X	7%
Other	4	(1%)	10	(1%)

5.1.5 Ecotoxicity Potential

Table 14 separates the ecotoxicity results into those associated with direct contributions from water cycle streams (i.e. land application of biosolids and effluent, and effluent discharge directly to waterways), and those incurred indirectly (e.g. via power generation, transport or the manufacture of materials). The direct emission pathways dominate the *Freshwater Ecotoxicity Potential* (FEP) and *Terrestrial Ecotoxicity Potential (TEP)* results, but there is a substantial contribution from indirect pathways (42-47%) for *Marine Ecotoxicity Potential* (MEP).

The main source of these indirect MEP impacts is fuel use, specifically the barium emissions associated with crude oil and natural gas supplies[8]. Biosolids delivery to farms, and to a lesser degree chemicals supply, are the major transport needs across the life cycle of the systems studied. Fuel use is also the main cause of the MEP impacts shown for the construction phase. Coal fired power generation is a notable source of indirect MEP impacts, because of both fuel use and airborne stack emissions. The increased power (use) and chemicals (transport) intensity of the 'Future infrastructure mix' water supply operations are the biggest point of difference between the two scenarios.

Organic micropollutants in wastewater make only a very minor contribution (<1%) to the MEP results. The biggest contributions are from the residual concentrations of chlorine (36-40%) and metals (13-14%) in the wastewater discharged directly to waterways. The increased recycling in the 'Future infrastructure mix' means a reduced fraction of effluent discharged to the sea, and therefore reduced MEP significance for these residual pollutants.

The ecotoxicity models assume a transfer of metal contaminants from biosolids (applied to farmlands) to adjacent waterways, and this is the dominant source of FEP (58-67%) and TEP (92-93%) impacts for both scenarios. The most significant metals to both these results are copper, zinc, selenium, nickel (all most likely from domestic hot water systems and personal care products such as shampoos) and mercury (most likely from trade waste). While the presence of these particular metals in biosolids is well established, Pritchard *et al*. (2010) argue that there is likely to be a very low ecotoxicological risk from biosolids metals for application to most Australian soils. Further investigation is required into how best to accommodate their data into LCA ecotoxicity models.

The biosolids reuse allowed a reduction in the use of synthetic fertilisers, some of which are well known to have high concentrations of heavy metals. However the associated FEP and TEP offsets were found to be negligible. This was due to the greater total biosolids volume required for equivalent soil fertilisation, plus the much greater copper and zinc concentrations in biosolids.

Runoff or leaching of trace metals and organic micropollutants in irrigated effluents also made a small but noticeable contribution (7-8%) to the FEP results. The 'Future infrastructure mix' introduces a direct input to freshwater ecosystems, with the IPR scheme discharging its product water into the local dam. However the high micropollutant rejection rates achieved by the AWTP mean that this pathway contributes very little (3%) to the overall FEP. The biggest indirect influences on the FEP results are the manufacture of chemicals (for use in the treatment plants) and fertiliser (offset by biosolids nutrient recycling). Wastewater irrigation makes only a minor contribution to the TEP results.

There is virtually no difference in the breakdown of the TEP results between the 'Traditional infrastructure mix' and 'Future infrastructure mix'. This is because the TEP results are almost exclusively associated with the metals load in biosolids, and the 'Future infrastructure mix' did not involve any substantial change to the way that biosolids was modelled.

[8] Barium compounds are used for drill lubrication by the oil and gas industries.

Table 14: Key contributors to the Ecotoxicity Potential (Marine, Freshwater, Terrestrial) results.

	Marine Ecotoxicity (t 1,4-DB eq/y)		Freshwater Ecotoxicity (t 1,4-DB eq/y)		Terrestrial Ecotoxicity (t 1,4-DB eq/y)	
	Traditional infr. mix	Future infr. mix	Traditional infr. mix	Future infr. mix	Traditional infr. mix	Future infr. mix
Total	**96 (100%)**	**259 (100%)**	**8 (100%)**	**24 (100%)**	**46 (100%)**	**127 (100%)**
Indirect pathways	40 (42%)	122 (47%)	2 (26%)	8 (32%)	1 (3%)	5 (4%)
power generation	4%	8%	1%	2%	1%	1%
chemicals manufacture	3%	3%	10%	17%	1%	1%
chemicals transport	5%	7%	<1%	<1%	<1%	<1%
biosolids transport	18%	19%	1%	1%	<1%	<1%
fertiliser manufacture	-1%	-1%	-4%	-3%	<-1%	<-1%
fertiliser transport	<-1%	<-1%	<-1%	<-1%	<-1%	<-1%
other	13%	11%	16%	15%	2%	2%
WW to sea	53 (56%)	129 (50%)	0 (<1%)	0 (<1%)	0 (<1%)	1 (<1%)
	chlorine 40%	chlorine 36%	chlorine <1%	chlorine <1%	chlorine <1%	chlorine <1%
	organics <1%	organics <1%	organics <1%	organics <1%	organics <1%	organics <1%
	Mn 12%	Mn 11%				
	Hg 1%	Hg 1%				
	Ba 1%	Ba 1%				
WW to dam	0 (0%)	1 (<1%)	0 (0%)	1 (3%)	0 (0%)	0 (<1%)
	chlorine 0%	chlorine 0%	chlorine 0%	chlorine 0%	chlorine 0%	chlorine 0%
	organics <1%	organics <1%	organics <1%	organics <1%	organics <1%	organics <1%
		Ba <1%		Mn 2%		
				Hg <1%		
WW to land	0 (<1%)	1 (<1%)	1 (8%)	2 (7%)	2 (4%)	5 (4%)
	chlorine 0%	chlorine 0%	chlorine 0%	chlorine 0%	chlorine 0%	chlorine 0%
	organics <1%	organics <1%	organics 4%	organics 4%	organics 1%	organics 1%
	V <1%	V <1%	V 2%	V 2%	V 1%	V 1%
	Ni <1%	Ni <1%	Ni <1%	Ni <1%	Zn <1%	Zn <1%
			Ba <1%	Ba <1%		
Biosolids to land	2 (2%)	6 (2%)	5 (67%)	14 (58%)	43 (93%)	117 (92%)
	organics <1%	organics <1%	organics <1%	organics <1%	organics <1%	organics
	Cu 1%	Cu 1%	Cu 43%	Cu 37%	Cu 66%	Cu 66%
	Se 1%	Se 1%	Se 15%	Se 13%	Se 3%	Se 3%
			Zn 5%	Zn 4%	Zn 17%	Zn 17%
			Ni 3%	Ni 3%	Hg 5%	Hg 5%
Offset fertiliser use	0 (<-1%)	0 (<-1%)	0 (<-1%)	0 (<-1%)	0 (<-1%)	0 (<-1%)
	Se <-1%	Se <-1%	Se <-1%	Se <-1%	Zn <-1%	Zn <-1%
	Ni <-1%	Ni <-1%	Ni <-1%	Ni <-1%	Cd <-1%	Cd <-1%
	Hg <-1%	Hg <-1%	Hg <-1%	Hg <-1%	Hg <-1%	Hg <-1%

5.1.6 Human Toxicity Potential

As shown in Table 15, piping networks are the biggest contributor to the Human Toxicity Potential (HTP) impacts, predominantly from the steel manufacturing process. Steel pipes make up only ~4% (by length) of the total Gold Coast piping network, suggesting that the steel manufacturing inventory data warrants more careful scrutiny if this impact category were to be included in the decision making process.

The other main contributor to the HTP results are the airborne emissions associated with coal fired power generation, particularly for the 'Future infrastructure mix' with its reliance on power-intensive water supply options.

Table 15: Key contributors to the Human Toxicity Potential results.

	Human Toxicity Potential (kt 1,4-DB eq/y)			
	Traditional		Future	
Total	**4**	**(100%)**	**14**	**(100%)**
Indirect pathways	4	(94%)	14	(96%)
power generation		17%		27%
chemicals supply		3%		3%
biosolids transport		4%		3%
offset fertilisers		<-1%		<-1%
construction - networks		66%		51%
construction - other		4%		12%
other		<-1%		<1%
WW to sea	0	(3%)	0	(2%)
	chlorine	2%	chlorine	2%
	organics	0%	organics	<1%
	metals	<1%	metals	<1%
WW to dam	0	(0%)	0	(<1%)
	chlorine	0%	chlorine	0%
	organics	0%	organics	0%
	metals	0%	metals	<1%
WW to land	0	(<1%)	0	(<1%)
	chlorine	<1%	chlorine	1%
	organics	0%	organics	0%
	metals	<1%	metals	<1%
Biosolids to land	0	(3%)	0	(2%)
	chlorine	2%	chlorine	3%
	organics	<1%	organics	2%
	metals	3%	metals	2%
Offset fertiliser use	0	(<-1%)	0	(<-1%)
	metals	<-1%	metals	<-1%

5.2 Comparing the Overall Impacts

This section provides some perspective on the overall scale of the results in each of the impact categories. This was done in two steps.

Firstly, total impact potential estimates were generated with Monte-Carlo simulations run separately for each scenario. Median values, and the 95th percentile confidence interval for each of the results, were taken from this modelling.

Secondly, these results were benchmarked against an estimate of the total Australian impact in each category. This provides some perspective on how the environmental impact potentials might be prioritised from the broader perspective of society as a whole. To do this, the result for each impact category was normalised against (divided by) the equivalent impact potential for the Australian economy dataset described in Section 4.6.

The results of these two steps are presented in Figure 6, with each impact potential expressed as a percentage contribution to the overall Australian result. It should be noted that the error bars reflect only the uncertainty associated with the urban water system results, and do not account for any uncertainty associated with the Australian impact data nor the underpinning impact models.

To facilitate comparison of the two scenarios, the ratios of absolute change ('Future' divided by 'Traditional') in the median results for each impact category are also shown. These can be directly compared to the 2.6 fold increase in household numbers under the 'Future' scenario (see Table 2).

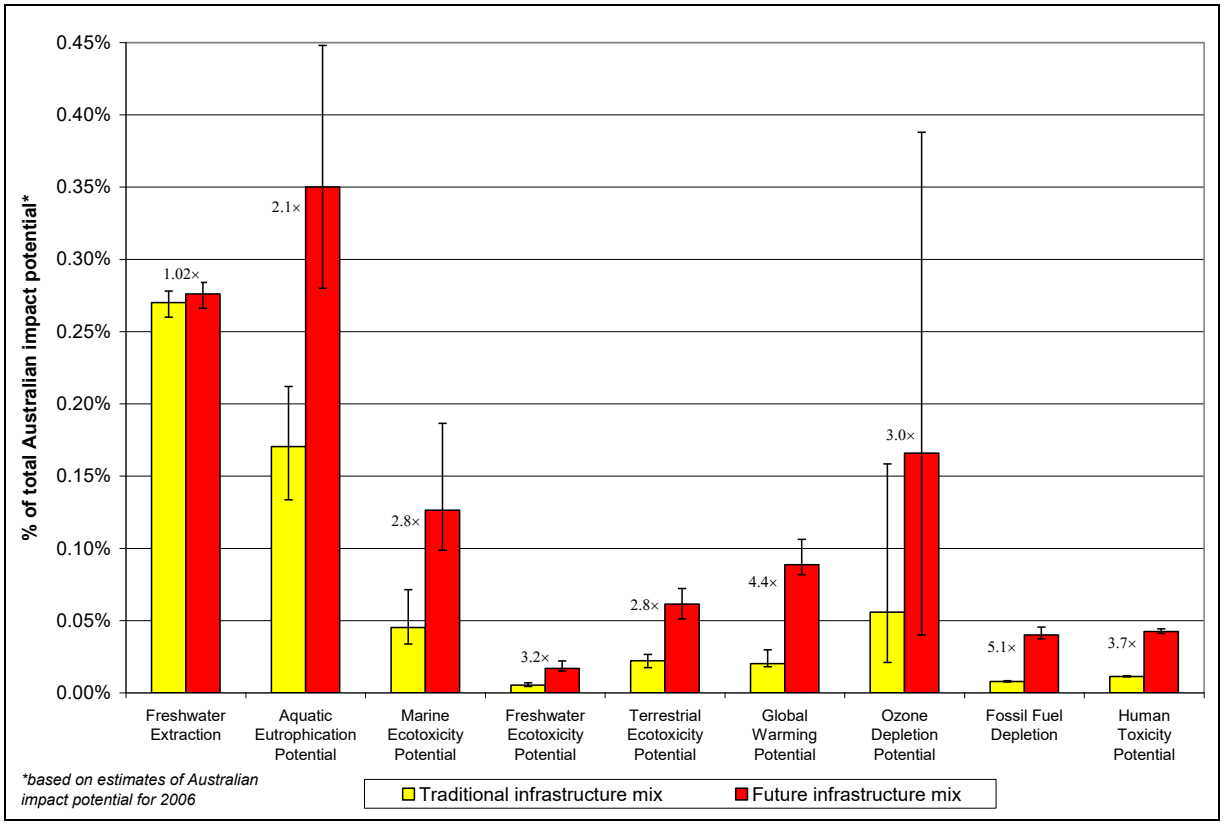

Figure 6: Normalised results (median and 95th percentile confidence interval) for the infrastructure scenarios.

5.2.1 Comparison of the Scenarios

The smallest absolute changes are for *Freshwater Extraction* and, to a lesser degree, *Aquatic Eutrophication Potential*. These encompass the issues (environmental flow management, and STP nutrient discharge) that have traditionally been the dominant priority for urban water managers.

The infrastructure mix included in the 'Future' scenario reflects a clear focus on minimising impacts in these two areas. For example, the focus on developing alternative water supply sources is in part a response to environmental constraints imposed on the level of freshwater extraction from the region's river systems. Also, licensing constraints applied to recently constructed AWTPs have enforced lower overall nutrient discharge loads than were allowed for the STPs. As a consequence, the increases in *Freshwater Extraction* (1.02×) and *Aquatic Eutrophication Potential* (2.1×) are much less than the increase in population associated with the 'Future infrastructure mix' scenario.

However Figure 6 highlights that the design of the 'Future infrastructure mix' comes at the cost of substantial increases in all the other impact categories considered. Some (*Marine Ecotoxicity Potential*, *Terrestrial Ecotoxicity Potential*, *Ozone Depletion Potential*) increase more or less in line with the increased population. Others (*Freshwater Ecotoxicity Potential*, *Global Warming Potential*, *Fossil Fuel Depletion*) all increase by more than the equivalent population increase, largely because the adoption of the alternative water supply systems increases the overall intensity of power and chemicals use for the urban water system. This increase in power use also contributed to the substantial increase (3.7×) in *Human Toxicity Potential* for the 'Future infrastructure mix', along with the construction required for the additional piping systems of the alternative water supply systems. For each of the impact categories, more detail on the differences between the two infrastructure scenarios is provided in Section 6.

The error bars in Figure 6 indicate that, for most of the impact categories, the population driven impact growth is more substantial than the combined inventory uncertainties that were modelled. While the error bar spans do indicate the large combined uncertainties involved with some of the impact results (particularly *Aquatic Eutrophication Potential*, *Marine Ecotoxicity Potential* and *Ozone Depletion Potential*) for the urban water system, the overlapping confidence intervals for *Freshwater Extraction* and *Ozone Depletion Potential* cannot be taken to indicate a lack of statistical significance in the comparison of the median results. Comparing these independently run Monte-Carlo simulations in this way does not account for parameters that should be correlated across the two scenarios. For example, the major cause of the large spread shown for the *Ozone Depletion Potential* is the uncertainty associated with N_2O emissions from sewage treatment plants. As the two scenarios involve essentially identical sewage treatment processes, whatever assumptions are used for this N_2O emission parameter should be correlated (identical) across both scenarios.

5.2.2 Implications of the Impact Growth

While control of population growth is not under the remit of SEQ urban water planners, they will be affected by growth-driven increases in environmental impacts of the urban water system. This will be a particular concern for issues where future policy direction might favour absolute constraints on impact growth. *Ozone Depletion Potential, Global Warming Potential* and *Fossil Fuel Depletion* are examples where there is substantial scientific and policy debate on the need for such action. Yet Figure 6 shows these particular impact categories to have some of the largest increases under the 'Future infrastructure mix' scenario.

As a result of the shift from in environmental burden from traditional (i.e.: *Freshwater Extraction* and *Aquatic Eutrophication Potential*) to non-traditional concerns, Figure 6 shows a substantial change in the profile of normalised results for the 'Future infrastructure mix'. While the recent prioritisation on environmental flow management and nutrient discharge reduction reflects historical social concerns, Figure 6 suggests that future pressures for environmental mitigation by the urban water sector might be spread across a wider range of issues.

The 'Future' infrastructure mix includes a range of options that are currently being adopted across SEQ. In all cases other than for rainwater tanks, this involves long term infrastructure commitments with large associated opportunity costs for any future shifts in direction. If near-term decision making does not account for this wider spread of environmental issues, the region may be at risk of committing to urban water system futures with an unnecessarily high overall environmental burden.

5.3 Prioritising the Causative Parameters

Section 5.1 highlighted that, in some cases, one impact category can be dominated by a major contribution from one source or activity (such as secondary effluent nutrient discharges to the sea). In other cases an activity (such as STP power use) makes smaller contributions to the results across a number of impact categories. What is lacking is some indication of how to relate and compare the overall contribution of these different sources of impact.

One means of doing this is to combine the normalised impact potential results (Figure 6) with the impact breakdowns provided in Table 11 to Table 15. The results of this approach are summarised in Table 16. It lists those elements of water supply and wastewater treatment operations that were identified (in Section 5.1) as key contributors to one or more of the impact results. This presents a list of operational parameters that water utility managers have some capacity to manipulate. For each, the normalised results are shown by impact category, and then summed. The final column shows how much of the Gold Coast's overall contribution (to the total Australian impact potential) can be attributed to each parameter. Those making an overall contribution greater than 1% are highlighted. Those that feature because they make a large contribution to one particular impact category are shown in bold.

By their nature however, midpoint indicators of impact potential (such as used here) cannot be directly compared for their contribution to an overall environmental burden. This is because the degree that each translates to actual environmental damage will vary across the impact categories. Consequently, analysis that sums results in this way should be interpreted cautiously.

Recognising this, the approach used in this section provides an indication of how various parameters might compare in relevance. Summing the normalised results invokes an equal weighting to each of the impact categories, implying that each is of equal importance. The summation step of Table 16 therefore provides a useful perspective if the ultimate goal is to fully mitigate all potential impacts.

Table 16: Normalised impact results for each key parameter identified in Section 5.1.

		1000 × normalised impact potentials[1,2]									Sum of potentials[3]	
Item (activity / source)		FWE	EP	MEP	FEP	TEP	GWP	ODP	FFD	HTP	Item	% of total
Dam	**water use**	**287**									**287**	**24%**
WW discharge to sea	**nutrients**		**291**								**291**	**25%**
	metals			**18**	**<1**	**<1**					**19**	**2%**
	organics			<1	<1	<1					0	0%
	chlorine			**48**	**<1**	**<1**					**48**	**4%**
	pumping power	<1	1	<1	<1	<1	3	<1	1		6	1%
WW discharge to dam	nutrients		1								1	0%
	metals			<1	<1	<1					1	0%
	organics			<1	<1	<1					0	0%
	chlorine										0	0%
	pumping power	<1	<1	<1	<1	<1	2	<1	<1		4	0%
WW reuse	**volumetric offset**	**-14**									**-14**	**-1%**
	nutrients										0	0%
	metals			<1	<1	1					2	0%
	organics			<1	<1	<1					1	0%
	chlorine										0	0%
	pumping power	<1	<1	<1	<1	<1	<1	<1	<1		2	0%
Biosolids to farms	**nutrients**		**92**								**92**	**8%**
	metals			**3**	**10**	**57**					**70**	**6%**
	organics										0	0%
	transport	<1	2	25	<1	<1	2	<1	<1		30	3%
Power use	tanks	<1	2	<1	<1	<1	5	<1	3		12	1%
	WTP	<1	<1	<1	<1	<1	2	<1	<1		4	0%
	mains networks	<1	<1	<1	<1	<1	2	<1	<1		4	0%
	desal	2	11	5	<1	<1	28	2	15		63	5%
	sewer	<1	3	1	<1	<1	7	<1	4		15	1%
	STP	<1	5	2	<1	<1	12	<1	6		28	2%
	AWTP	<1	1	<1	<1	<1	3	<1	2		8	1%
Fugitives	**N2O (WWT)**						**6**	**151**			**157**	**13%**
	CH4 (WWT)						3				3	0%
	CH4 (dam)						2				2	0%
	CO2 (WWT)						1				1	0%
Chemicals	m'facture - floculation (P removal)										0	0%
	m'facture - floculation (other)										0	0%
	m'facture - denitrification	<1	<1	<1	<1	<1	<1	<1	<1		1	0%
	m'facture - others	<1	<1	3	2	<1	1	<1	<1		8	1%
	transport (all)	<1	<1	10	<1	<1	<1	<1	<1		12	1%
Fertiliser (offsets)	manufacture	<-1	<-1	-1	<-1	<-1	<-1	<-1	<-1		-4	0%
	transport	<-1	<-1	<-1	<-1	<-1	<-1	<-1	<-1		0	0%
	nutrients		**-22**								**-22**	**-2%**
	metals			<-1	<-1	<-1					0	0%
Other		5	8	11	0.1	1	6	0.3	4	0	35	3%
Total		**279**	**395**	**125**	**12**	**59**	**85**	**153**	**34**	**0**	**1181**	**100%**

1. each value represents the contribution (10^{-3}%) of that parameter to the total impact potential of the Australian economy.
2. zero contributions are not shown; contributions of less than 1×10-3% are greyed out.
3. parameters with an overall contribution greater than 1% are shaded; those that achieve this because of a dominant contribution to a single impact category are shown in bold.

Table 16 shows that dam water use and STP nutrient discharges make the single biggest contributions to the total normalised score. These are the two issues that have traditionally been the priority of urban water planners and managers. However Table 16 highlights that there are a number of other significant contributions. Nutrient losses from biosolids and synthetic fertilisers both feature, because of their significance to the overall *Aquatic Eutrophication Potential*. Biosolids and wastewater pollutants (chlorine, metals and organics) are also substantial because of their link to the *Ecotoxicity* results. N_2O emissions feature because they dominate the results for *Ozone Depletion Potential*. As highlighted in previous sections, all these particular issues are subject to large uncertainties in the inventory modelling. The uncertainties associated with the ecotoxicity and ozone depletion impact models (see Section 5.1) should also not be overlooked.

A number of the highlighted parameters feature because they make small contributions to many of the impact results. Power use falls into this category. While the total power use contribution in Table 16 is ~12%, this is disaggregated across a number of mostly independent inputs (e.g. rainwater tank energy use is independent of sewage treatment energy use). Transport is another issue in this category, being particularly relevant to the disposal of biosolids and the supply of chemicals.

It is recognised that in many cases these parameters are not strictly independent (e.g. increasing power input can decrease treated water quality), and therefore addressing one parameter might increase the impacts related to another. Even so, Table 16 provides a quantitative means for how one might consider the tradeoffs involved.

6. UNDERSTANDING THE CHANGES IN OVERALL IMPACT

This chapter provides additional analysis to support interpretation of the difference in overall results for the two scenarios. The focus here is on the implications of the changed infrastructure mix, separating out those implications associated with the increased population. This was done by comparing the 'Traditional infrastructure mix' and 'Future infrastructure mix' scenarios on a per-household basis. For this task, both scenarios were restricted to the 'urban' portion of the households (i.e. those connected to both mains water supply and the centralised sewer network). The 20,000 'peri-urban' households were excluded.

The functional unit for the analysis in this chapter is therefore:

> *The provision of water supply and wastewater services, for 1 year, to an urban population for the Gold Coast region of SEQ.*

Identifying the key differences between the two overall infrastructure selections provides information relevant to Research Objectives 1, 2 and 5.

These overall differences are illustrated in Figure 7. These results were generated using the default assumptions for each parameter (as described in Section 4.3). Given the small differences indicated in Figure 7, and the large uncertainties noted in Section 4.3 for key inventory parameters, statistical analysis would be required for more robust comparison of the changes in averaged impact.

However analysis based on the default assumptions allowed identification of the key contributions to the differences found between the two scenarios. The differences for each impact category are broken down in Table 17 to Table 24. It should be noted that the scale of the values shown are dependent on the household water use assumptions that underpin this analysis. Linear extrapolation of these results for different household demand assumptions is not possible. The tables should therefore only be used for *comparing* the two scenarios considered here.

6.1 Results

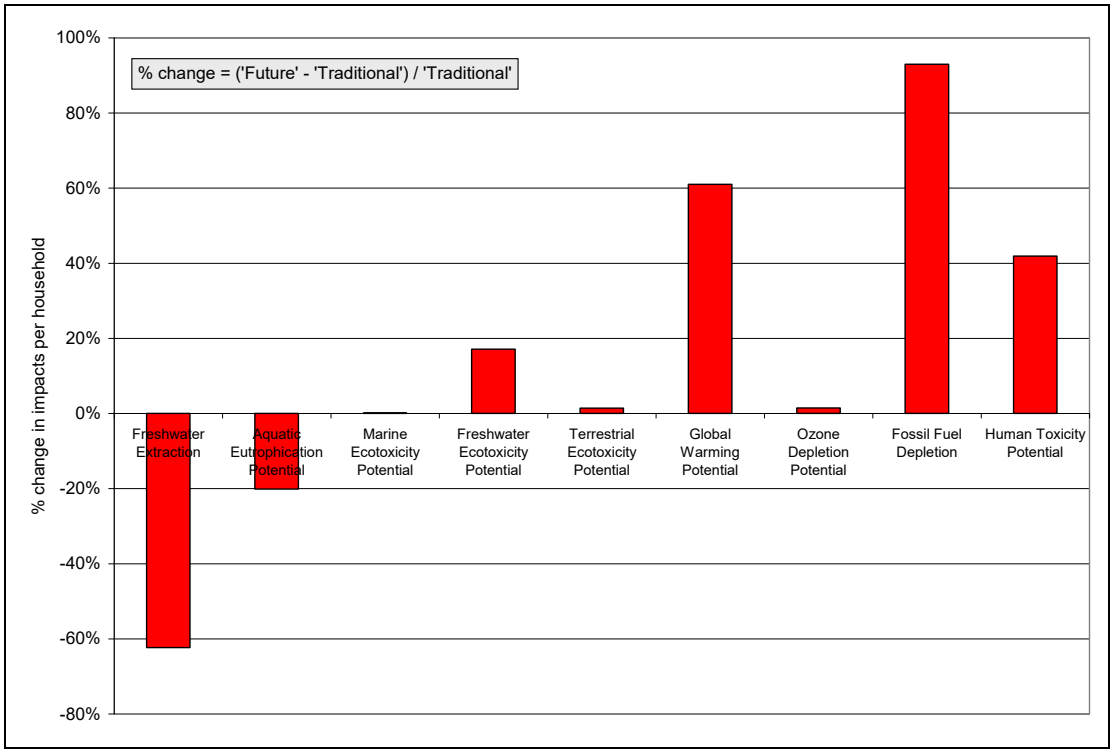

Figure 7: Comparison of 'Future' and 'Traditional' scenarios on a per-household basis.

6.1.1 Freshwater Extraction and Eutrophication Potential

Figure 7 indicates a significant reduction in the per-capita impact for *Freshwater Extraction*, thanks to the shift towards non-dam based sources (desalination, water recycling, rainwater tanks) in the 'Future' water supply mix. The substantial increase in water recycling also delivered a reduction in *Aquatic Eutrophication Potential* (AEP). The benefits (a 26% reduction in AEP) of diverting secondary treated effluent away from the normal marine discharge point are illustrated in Table 17. Most of this diversion was due to the AWTP of the IPR system, which simply shifts the majority of the discharge from the sea to the freshwater dam. As our AEP model did not distinguish between the nature of the aquatic receiving environments, the change in discharge point itself did not deliver the AEP benefits for the IPR system. Instead, they resulted from the additional phosphorous (by chemical flocculation) and nitrogen (by denitrification) removal of the AWTP. This is reflected in the low AEP associated with the IPR product water and ROC shown in Table 17.

Table 17: Breakdown of per household differences in Aquatic Eutrophication Potential (AEP).

	Traditional (T) (kg PO4e/hh)	Future (F) (kg PO4e/hh)	Change = F-T (kg PO4e/hh)	% Change = (F-T)/ΣT*100 (%)
WW to sea	94.2	64.4	-29.9	-26%
IPR product	--	0.3	0.3	0.2%
IPR ROC	--	2.5	2.5	2%
WW irrigation	0.03	0.03	0.002	0.001%
Biosolids reuse	22.2	22.6	0.4	0.4%
Offset fertiliser use	-5.4	-5.4	0.0	0.0%
Power generation	2.7	6.0	3.3	3%
Other	0.9	1.0	0.1	0.1%
Total (Σ)	**115.2**	**92.0**	**-23.2**	**-20%**

6.1.2 Freshwater Ecotoxicity Potential

Table 18 provides a breakdown of the *Freshwater Ecotoxicity Potential* (FEP) increase shown in Figure 7. The main cause of the change is the increase in both intensity and range of chemicals used for the recycling and desalination systems of the 'Future infrastructure mix'. Recycling of water into the local dam (as part of the IPR scheme) also contributed to the increase in FEP results for the 'Future infrastructure mix'. However the implications of this were minimised by the effective micropollutant removal processes included in the IPR model. The small increase shown for the biosolids disposal was caused by the additional diversion of metals to biosolids by the Class A+ AWTP.

Table 18: Breakdown of per household differences in Freshwater Ecotoxicity Potential (FEP).

	Traditional (T) (kg 1-4DCBe/hh)	Future (F) (kg 1-4DCBe/hh)	Change = F-T (kg 1-4DCBe/hh)	% Change = (F-T)/ΣT*100 (%)
IPR product - chlorine	--	0	0	0%
IPR product - metals	--	0.1	0.1	3%
IPR product - organics	--	0	0	0%
WW to soil - metals	0.066	0.068	0.002	0.11%
WW to soil - organics	0.079	0.082	0.003	0.16%
Biosolids to soil	1.240	1.255	0.015	1%
fertiliser metals	-0.004	-0.004	0.000	0.01%
Power generation	0.020	0.045	0.025	1%
Biosolids transport	0.026	0.027	0.000	0%
Fertiliser manufacture	-0.068	-0.066	0.002	0%
Chemicals manufacture	0.181	0.362	0.181	10%
Chemicals transport	0.007	0.010	0.003	0.2%
Construction	0.265	0.266	0.002	0.1%
Other	0.030	0.050	0.019	1%
Total (Σ)	**1.8**	**2.2**	**0.3**	**17%**

6.1.3 Marine Ecotoxicity Potential

The inclusion of the two recycling systems means that the 'Future infrastructure mix' has a lower average discharge of secondary effluent directly to the sea. Table 19 shows that the associated reduction in discharge of residual chlorine gives a substantial reduction in *Marine Ecotoxicity Potential (MEP)*. While the reduced secondary effluent discharge might also reduce the metals discharges directly to the sea, the IPR scheme (which has the biggest influence on the secondary effluent balance) partitions most of those metals to the RO concentrate. In our hypothetical IPR system, the ROC concentrate (and associated metals) was pumped to the same marine discharge point as would have been used for secondary effluent discharge. The secondary effluent diversion therefore played only a small part in the metals related FEP benefits. The net reduction in MEP from metals discharges to sea was instead a result of the manganese removal achieved at the Pimpama AWTP as a precursor to Class A+ effluent reuse.

Table 19 shows an increase in the indirect MEP associated with chemicals transport and power generation - these can be attributed to the relatively chemicals and power intensive water supply systems (recycling, SWRO, rainwater tanks) included in the 'Future' scenario. The combination of these counter-balancing effects was a negligible net change in average (per household) MEP results for the 'Future' scenario.

Table 19: Breakdown of per household differences in Marine Ecotoxicity Potential (MEP).

	Traditional (T) (kg 1-4DCBe/hh)	Future (F) (kg 1-4DCBe/hh)	Change = F-T (kg 1-4DCBe/hh)	% Change = (F-T)/ΣT*100 (%)
WW to sea - chlorine	9.5	8.4	-1.1	-5%
WW to sea - metals	3.7	2.6	-1.0	-4%
WW to sea - organics	0.1	0.1	-0.03	-0.1%
IPR product - chlorine	--	0	0	0%
IPR product - metals	--	0.1	0.1	1%
IPR product - organics	--	0	0	0%
IPR ROC - chlorine	--	0	0	0%
IPR ROC - metals	--	0.6	0.6	3%
IPR ROC - organics	--	0	0	0%
Power generation	0.84	1.87	1.03	4%
Biosolids transport	4.34	4.39	0.05	0.2%
Fertiliser manufacture	-0.21	-0.21	0.00	0.02%
Chemicals manufacture	0.51	0.67	0.16	1%
Chemicals transport	1.15	1.72	0.57	2%
Construction	2.50	2.15	-0.35	-2%
Other	0.95	1.00	0.05	0.2%
Total (Σ)	**23.4**	**23.4**	**0.0**	**0.1%**

6.1.4 Terrestrial Ecotoxicity Potential

Figure 7 and Table 20 show a small net increase in per-capita *Terrestrial Ecotoxicity Potential* (TEP) for the 'Future infrastructure mix', with the biggest change associated with the contribution from biosolids metals. This is caused by the additional diversion of metals to biosolids by the AWTP of the Class A+ system.

6.1.5 Ozone Depletion Potential

Figure 7 also shows only a very small increase in *Ozone Depletion Potential* (ODP) for the 'Future infrastructure mix'. Section 5.1.3 identified that the ODP results are dominated by fugitive nitrous oxide (N_2O) emissions from the wastewater system. Since the 'Future' scenario involves the scaling up of wastewater operations largely in proportion to the number of additional households included, the main point of difference in terms of N_2O emissions was the extra denitrification resulting from the advanced wastewater treatment. However, Table 21 shows that the main increase in ODP comes from the increased overall power use under the 'Future' scenario.

Table 20: Breakdown of per household differences in Terrestrial Ecotoxicity Potential (TEP).

	Traditional (T) (kg 1-4DCBe/hh)	Future (F) (kg 1-4DCBe/hh)	Change = F-T (kg 1-4DCBe/hh)	% Change = (F-T)/ΣT*100 (%)
WW to soil - metals	0.268	0.274	0.006	0.05%
WW to soil - organics	0.143	0.149	0.005	0.05%
Biosolids to soil	10.6	10.7	0.1	0.50%
fertiliser metals	0.0	0.0	0.0	0.01%
Power generation	0.06	0.13	0.07	0.63%
Biosolids transport	0	0	0	0%
Fertiliser manufacture	0	0	0	0%
Chemicals manufacture	0.09	0.09	0.0	-0.01%
Chemicals transport	0	0	0	0.01%
Construction	0.160	0.163	0.003	0.02%
Other	0.1	0.1	0.0	0.14%
Total (Σ)	**11.4**	**11.5**	**0.2**	**1%**

Table 21: Breakdown of per household differences in Ozone Depletion Potential (ODP).

	Traditional (T) (kg CFC-11e/hh)	Future (F) (kg CFC-11e/hh)	Change = F-T (kg CFC-11e/hh)	% Change = (F-T)/ΣT*100 (%)
Power generation	0.002	0.005	0.002	1.1%
Fugitives - WWT	0.2260	0.2264	0.0004	0.2%
Other	0.0017	0.0021	0.0004	0.2%
Total (Σ)	**0.230**	**0.233**	**0.003**	**1.4%**

6.1.6 Global Warming Potential and Fossil Fuel Depletion

Figure 7 shows that the biggest increases for the 'Future infrastructure mix' are in *Global Warming Potential* (GWP) and *Fossil Fuel Depletion* (FFD). Table 22 and Table 23 highlight that this is almost entirely associated with an increase in power generation. The alternative water supply options (water recycling, seawater desalination, rainwater tanks) included in the 'Future infrastructure mix' are all more energy intensive than the dam based mains water supply at the Gold Coast. As a consequence, the overall energy intensity of the 'Future infrastructure mix' was nearly double that of the 'Traditional infrastructure mix'.

Table 22: Breakdown of per household differences in Global Warming Potential (GWP).

	Traditional (T) (t CO_2e/hh)	Future (F) (t CO_2e/hh)	Change = F-T (t CO_2e/hh)	% Change = (F-T)/ΣT*100 (%)
Power generation	15.3	33.9	18.6	64%
Fugitives - WWT	5.7	5.7	-0.1	0%
Fugitives - dam	1.8	0.8	-1.0	-3%
Biosolids transport	1.2	1.2	0.0	0%
Fertiliser manufacture	-0.3	-0.3	0.0	0%
Chemicals manufacture	1.5	1.5	0.0	0%
Chemicals transport	0.3	0.5	0.2	1%
Construction	2.8	2.7	-0.1	0%
Other	0.8	0.9	0.2	1%
Total (Σ)	**29.1**	**46.9**	**17.8**	**61%**

6.1.7 Human Toxicity Potential

Increased power use was also the biggest cause of increases in *Human Toxicity Potential* (HTP) under the 'Future' scenario (Table 24). The other main difference was the increase in steel inventories for the additional piping networks for the desalination supply, discharge of AWTP product water into the dam, and the Class A+ third pipe reticulation. These are the dominant cause of the construction difference for HTP shown in Table 24.

Table 23: Breakdown of per household differences in Fossil Fuel Depletion (FFD).

	Traditional (T) (kg oil-e/hh)	Future (F) (kg oil-e/hh)	Change = F-T (kg oil-e/hh)	% Change = (F-T)/ΣT*100 (%)
Power generation	3,730	8,281	4,551	89%
Biosolids transport	179	181	2	0.04%
Fertiliser manufacture	-144	-146	-2	0.0%
Chemicals manufacture	384	365	-20	-0.4%
Chemicals transport	48	71	23	0.5%
Construction	809	944	135	2.7%
Other	88	134	45	0.9%
Total (Σ)	**5,094**	**9,830**	**4,736**	**93%**

Table 24: Breakdown of per household differences in Human Toxicity Potential (HTP).

	Traditional (T) (kg 1-4DCBe/hh)	Future (F) (kg 1-4DCBe/hh)	Change = F-T (kg 1-4DCBe/hh)	% Change = (F-T)/ΣT*100 (%)
WW to sea	23.5	24.0	0.6	0.1%
IPR product	--	0	0	0%
IPR ROC	--	0	0	0%
WW to soil	2.34	2.21	-0.13	-0.015%
Biosolids to soil	26.9	26.9	0.0	0.0%
fertiliser metals	0.0	0.0	0.0	0.0%
Power generation	158	351	193	22%
Biosolids transport	39.9	40.4	0.5	0.05%
Fertiliser manufacture	-2.1	-2.0	0.1	0.01%
Chemicals manufacture	17.3	19.9	2.6	0.3%
Chemicals transport	10.6	15.9	5.2	0.6%
Construction	609	780	171	19%
Other	9.5	12.3	2.8	0%
Total (Σ)	**896**	**1,271**	**375**	**42%**

7. COMPARISON OF THE NEW WATER SUPPLY OPTIONS

This chapter directly compares the four alternative water supply approaches included in the 'Future infrastructure mix' – Class A+ recycling, Indirect Potable Reuse (IPR), household rainwater tanks, and sea water desalination. The objective is to highlight and explain any tradeoffs involved in a choice between these systems. The results inform the findings for Research Objective 3, and the identification of important data gaps addresses Research Objective 5.

7.1 Methodology

7.1.1 Analysis

Inventories were generated using the default assumptions for each parameter (as described in Section 4.3). The scenarios were compared across those eight impact categories for which operational impacts were found to dominate the results in Chapter 4: *Freshwater Extraction*; *Aquatic Eutrophication Potential*; *Ecotoxicity Potential (Marine, Freshwater, Terrestrial)*; *Global Warming Potential*; *Ozone Depletion Potential*; and *Fossil Fuel Depletion*.

The results from this analysis were normalised in order to provide some perspective on the relative significance of any tradeoffs that might be apparent. To do this, the results were divided by the estimates of total impact potential for the 'Traditional' infrastructure mix of the Gold Coast (as calculated in Section 5.2). This benchmark gives an indication of the overall environmental burden of the urban water system - as it was before the introduction of these 'new' water supply measures. The normalised results therefore highlight which of the results would make the biggest change to the environmental impact potential of the traditional Gold Coast urban water system.

The key contributors to each impact category result were identified, and compared across the scenarios.

Finally, sensitivity analysis was undertaken by varying key assumptions on the configuration of the Class A+ and Rainwater Tank systems.

7.1.2 Basis for Comparison

From a water supply planning perspective, the fundamental requirement of these alternative technologies is to offset the need for growth in mains supply from traditional sources (typically dams or groundwater). The scenarios were therefore compared on the basis of their ability to offset a 'default' mains source, with the results expressed per unit-volume of mains water equivalent supply.

The comparisons are premised on the following key assumptions:

- The capacity of the **Class A+** and **Rainwater Tank** systems to offset mains water is a function of household water demand, as both are constrained to supplying specific end-uses at a specific number of households. The household water use profile that underpins this analysis is summarised in Table 3.
- Because their product water is distributed through the integrated mains network, the mains water offset by the **Desalination** and **IPR** systems was assumed to be independent of average household usage. Instead, it was assumed that there would be sufficient households connected to the mains to ensure that demand would absorb the full supply capacity of these systems. Both these scenarios assumed that the mains water would be reticulated within the current geographic footprint of the Gold Coast urban water system.
- Infrastructure construction inventories were allocated across the full life-time capacity of each system.

The functional unit for the analysis is:

> *Supply, to the urban Gold Coast community, of a volume of water equivalent to 1ML of mains supply.*

Table 25 summarises the basis for comparison of the four scenarios. The assumptions underpinning the calculation of the mains water offset for each of the scenarios are described in more detail in Section 7.1.3.

Table 25: Basis for the comparison of water supply scenarios.

Scenario	Comparison basis	Provided by…
Class A+	1 ML of mains equivalent	3.5 ML of AWTP throughput
IPR	1 ML of mains equivalent	1.3 ML of AWTP throughput
Rainwater Tank	1 ML of mains equivalent	1.4 ML of tank water supplied
Desal	1 ML of mains equivalent	1.1 ML of desal product water

7.1.3 Scenario Definition

The following sections summarise the system boundary and fundamental water balance for each of the four scenarios. Further description, and details on key assumptions and data sources, can be found in Section 4.3.

7.1.3.1 Class A+ Reuse

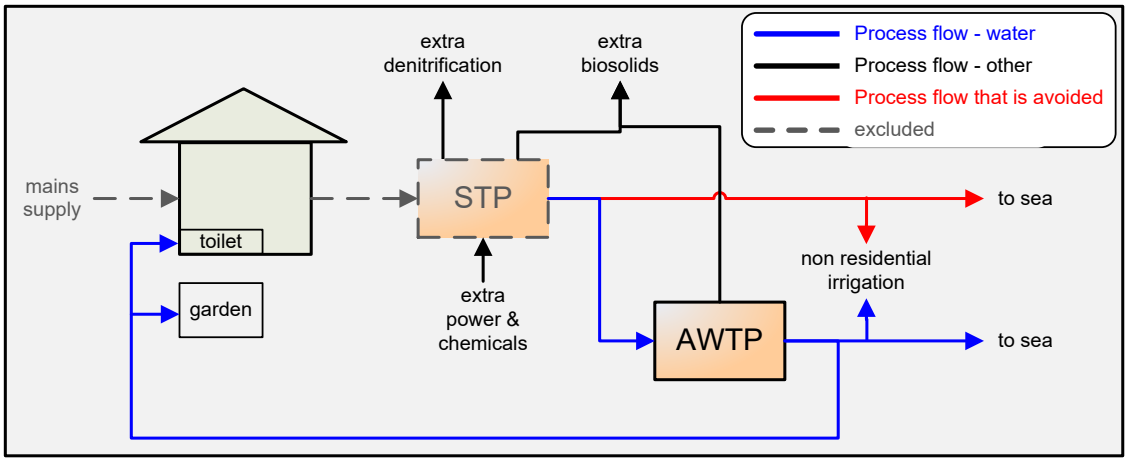

Figure 8: Class A+ reuse scenario - flow sheet for water supply comparison.

The Class A+ reuse system is illustrated in Figure 8. An advanced wastewater treatment plant (AWTP) treats the full secondary effluent discharge from the adjoining STP. Class A+ water is reticulated to all houses in the STP catchment, and used for all toilet and external demands. Class A+ water is also used to meet the default demand for non-residential Class B reuse. The mains water offset was calculated as the sum of the internal household reuse, and those portions of irrigation (residential and non-residential) that were assumed to displace mains use.

The unused Class A+ water is discharged to the sea. For the portion that is reused in toilets and presents again to the STP, it was assumed that:

- the nitrogen content is fully nitrified and denitrified in the STP[9], and the phosphorous content is fully removed by chemical precipitation; and
- the organic micropollutants are fully oxidised, and the metals report entirely to the STP biosolids.

[9] This assumes that there would be no accumulation in unbiodegradable soluble compounds. Planning for the Pimpama-Coomera Class A+ scheme suggested that a small increase (<1 mgN/L) in the unbiodegradable organic N fraction would occur in the system due to water recycling via toilet flushing. To our knowledge, there have been no investigations into the extent to which this increase has materialised.

7.1.3.2 Indirect Potable Reuse (IPR)

The IPR system is illustrated in Figure 9. An advanced wastewater treatment plant (AWTP) treats the full secondary effluent discharge from the adjoining STP. The AWTP product water is discharged into the local dam where it feeds into the existing mains water treatment and supply system. The assumptions for dam, water treatment plant, and mains distribution losses are described further in Section 4.3.3. These losses were accounted for in the calculation of mains water offsets delivered by the IPR system.

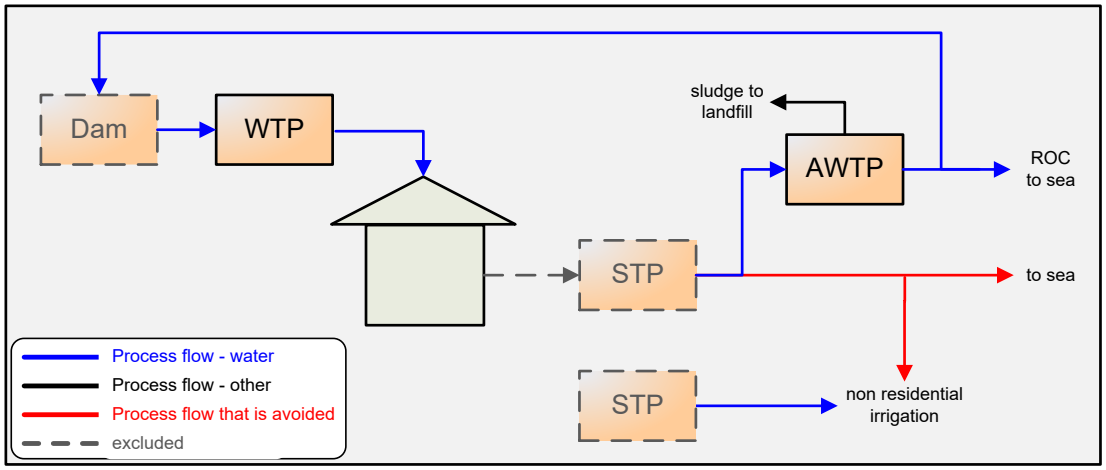

Figure 9: IPR scenario - flow sheet for water supply comparison.

The AWTP reject stream is discharged directly to the sea, and the AWTP sludge to landfill. The Class B reuse that would otherwise have been supplied from this STP is met by an increase in reuse from the other Gold Coast STPs.

7.1.3.3 Rainwater Tank

The Rainwater Tank scenario is illustrated in Figure 10. The 5,000L tanks (one per house) are connected to supply all demands for toilet, laundry (cold water only) and outdoor uses. The mains water offset accounted for the induced irrigation (over and above that which would have occurred from a mains supply) by subtracting this value from the total rainwater yield.

Two scenarios were considered, with mains backup water delivered either via top-up into the tank, or bypassing the tank pump through an automated switching device. The proportion of tanks with each backup system affects the ratio of tank delivery to rainwater yield, which in turn affects the calculated mains water offset.

7.1.3.4 Sea Water Desalination

The Desalination system is illustrated in Figure 11. Product water is pumped through a dedicated main, and then mixed into existing reservoirs of the Gold Coast mains supply network. It was assumed that these reservoirs supply the downstream network by gravity feed. Mains water supply was taken to be the actual production volume minus an allowance for distribution losses (see Section 4.3.3).

The RO reject stream is discharged back into the sea. Treatment plant sludge is trucked to landfill.

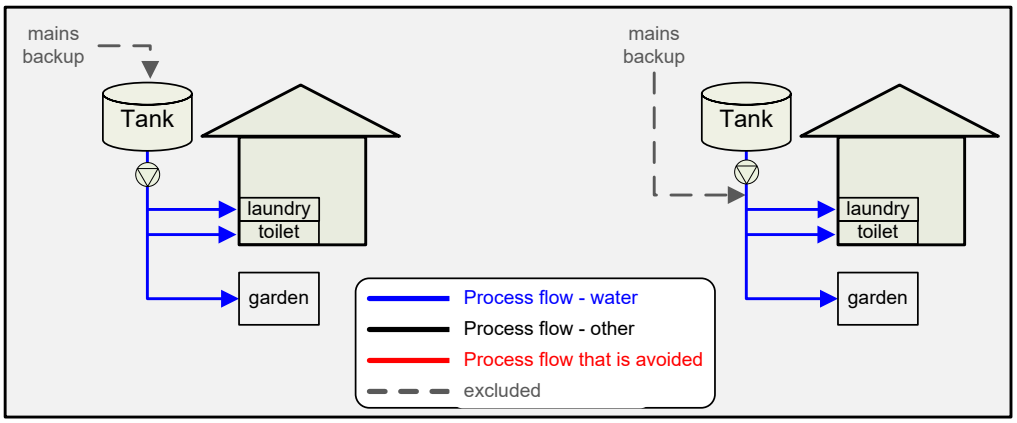

Figure 10: Rainwater Tank scenario - flow sheet for water supply comparison.

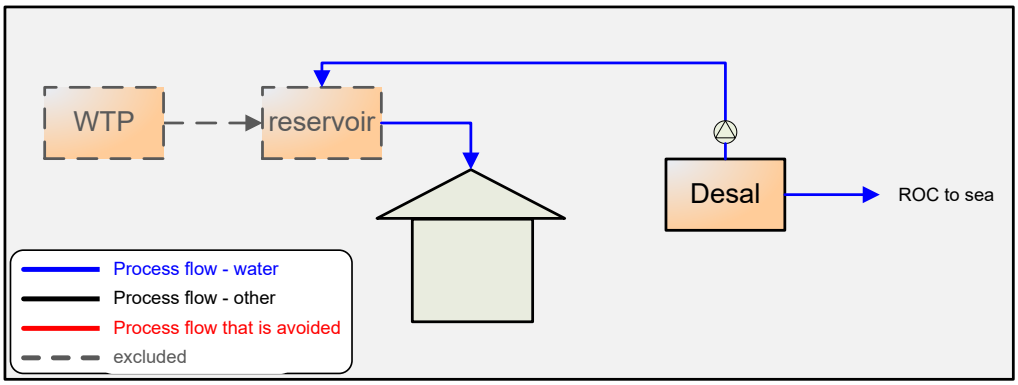

Figure 11: Desalination scenario - flow sheet for water supply comparison.

7.2 Results

Figure 12 compares the median results for each scenario, normalised against estimates of the total impact potential for the urban water system of the Gold Coast. To do this, the impact potentials calculated for the 'Traditional infrastructure mix' scenario in Section 5.1 were divided by the total mains-equivalent supply for that scenario. The results (per ML) for the four water supply options were then divided by the results (per ML) for the overall urban water system, with the normalised results expressed as a fraction on the y-axis of Figure 12.

A positive result in Figure 12 demonstrates that the infrastructure scenario incurs a negative impact (e.g. energy use) related to that impact category. A negative result means that the scenario delivers a net benefit (e.g. avoided nutrient discharge) compared to what would have occurred if that infrastructure was not in place. A normalised result of 1 indicates that the impact intensity (per ML of mains supply) for that water supply option is equal to the impact intensity (per ML of mains supply) of the entire (water supply + wastewater treatment) urban water system.

7.2.1 Freshwater Extraction

None of the scenarios involve a change to the amount of environmental water extracted from the Gold Coast dams. Section 5.1.1 highlighted that the embedded water in power generation, chemicals or materials supply is trivial compared to the direct dam water extraction associated with the conventional mains water supply at the Gold Coast. The *Freshwater Extraction* (FWE) associated with these four scenarios is therefore negligible when compared to that taking place across the full urban water system.

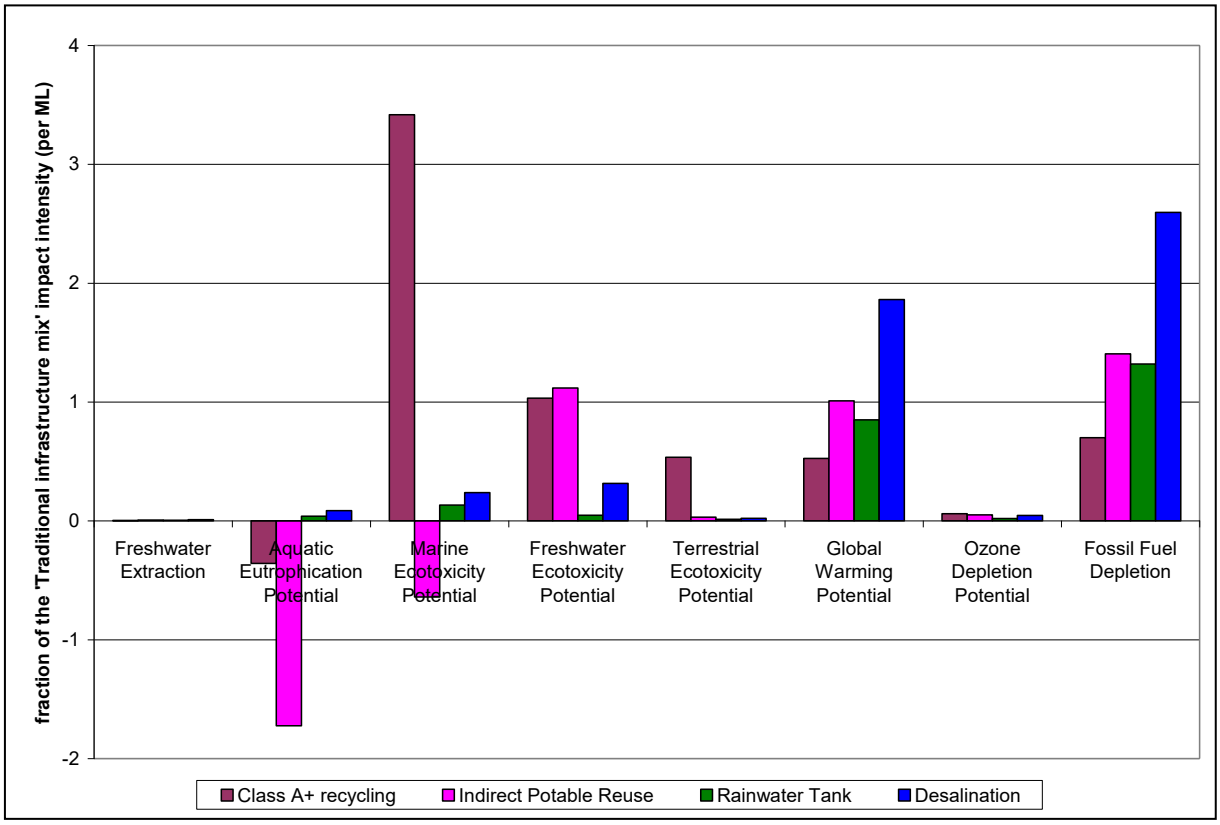

Figure 12: Normalised comparison of the four water supply scenarios.

7.2.2 Ozone Depletion Potential

Both the IPR and Class A+ recycling systems generate a small amount of N_2O from the additional denitrification required, and incur a small net increase in N_2O emissions associated with the partial transfer of effluent discharge from the sea to freshwater or terrestrial environments. However, the scale of these N_2O changes, and any indirect *Ozone Depletion Potential* (ODP) associated with power generation and materials manufacture, is small compared to the N_2O emissions associated with STP processing of the full Gold Coast sewage load. Figure 12 therefore shows the normalised ODP results of all four scenarios to be negligible.

7.2.3 Aquatic Eutrophication Potential

The two recycling systems deliver substantial benefits in terms of *Eutrophication Potential* (AEP). Table 26 highlights that the avoided secondary effluent discharge (direct to sea) far outweighs any indirect AEP incurred via power generation or materials use.

For the IPR system however, the full volume of AWTP output (whether product water discharged to a freshwater dam, or RO reject discharged to the sea) still reaches waterways. As the AEP model did not distinguish between the nature of the aquatic receiving environment, the change in discharge point did not in itself deliver the AEP benefits. Instead, the benefits result from the additional phosphorous (by chemical flocculation) and nitrogen (by denitrification) removal achieved by the AWTP.

For the Class A+ recycling system, the overall AEP benefits are much smaller because there remains a substantial release of surplus wastewater directly to the sea. This discharge would be reduced if the total reuse demand was greater; illustrating that the AEP results for the Class A+ system would be sensitive to any assumptions about household water use.

NO_X releases from power generation constitute the AEP burden of the rainwater tank and desalination scenarios, also making a minor contribution for the two recycling systems. Figure 12 highlights that such results are likely to be very minor from the perspective of the overall urban water system.

Table 26: Breakdown of Aquatic Eutrophication Potential (AEP) results.

Process	Unit	Class A+	IPR	Rain Tank	Desal
Total	**kg PO4--- eq**	**-3.3**	**-15.7**	**0.4**	**0.8**
Avoided discharge of STP effluent	kg PO4--- eq	-6.5	-18.3	x	x
Class A+ discharge to sea	kg PO4--- eq	2.9	x	x	x
Leaching/runoff from Class A+ irrigation	kg PO4--- eq	0.1	x	x	x
AWTP product water discharge (to dam)	kg PO4--- eq	x	0.2	x	x
AWTP RO reject discharge (to sea)	kg PO4--- eq	x	1.9	x	x
Power use	kg PO4--- eq	0.2	0.3	0.3	0.0
Other	kg PO4--- eq	0.0	0.1	0.0	0.8

7.2.4 Ecotoxicity Potential

Table 27 shows that the diversion of secondary treated effluent delivers a substantial *Marine Ecotoxicity Potential* (MEP) benefit for the IPR system, as it avoids the discharge of residual chlorine to the sea. The MEP benefits associated with changes in the metals balance are, however, relatively minor. This is because the majority of the secondary effluent metals are still discharged to the sea via the RO reject stream. Furthermore, a portion of the residual metals in the AWTP product water are assumed to transfer to the sea over the long term. As highlighted in Table 28, these residual product water contaminants also generate a *Freshwater Ecotoxicity Potential* (FEP) result for the IPR scenario.

Table 14 identified Manganese as the dominant metal contribution to secondary effluent MEP. The Pimpama AWTP captures the majority of effluent Manganese with chemical precipitation[10]. The resulting sludge is mixed with STP biosolids and applied to agricultural lands. The household Class A+ irrigation pathway also diverts residual product water micropollutants away from the marine environment. As illustrated in Table 27, the net result for the Class A+ system is a substantial MEP benefit associated with the removal of metals from the marine environment. However, Table 28 and Table 29 highlight a possible downside of diverting these metals by land application – irrigation and biosolids reuse make the dominant contributions to the *Terrestrial Ecotoxicity Potential* (TEP) and FEP shown in Figure 12 for the Class A+ system.

The Class A+ recycling also reduces the release of residual chlorine in secondary effluent discharges. However these benefits are small compared to the downside of discharging surplus Class A+ wastewater to the sea. Design constraints for the Pimpama AWTP mean that even this portion of the product flow is disinfected to the high residual chlorine concentrations required by health regulations for water recycling. The consequence is a substantial net increase in MEP for the Class A+ scenario in this analysis.

Also of note are the contributions to MEP and FEP from the supply of chemicals to the Class A+, IPR and desalination systems. The most substantial contribution was for the IPR scenario, with the indirect FEP related to chemicals manufacture being greater than that attributed to the discharge of product water micropollutants directly into the freshwater dam.

Power use was the other main source of indirect ecotoxicity impacts, and the biggest contributor to the results for the rainwater tank and desalination scenarios. However, Figure 12 suggests that the scale of ecotoxicity impacts for these two systems are mostly minor.

[10] Manganese removal is carried out primarily so that the Class A+ reuse does not cause discolouration of toilet bowls.

Table 27: Breakdown of Marine Ecotoxicity Potential (MEP) results.

Process	Unit	Class A+	IPR	Rain Tank	Desal
Total	**kg 1,4-DB eq**	**6.42**	**-1.20**	**0.25**	**0.45**
Avoided discharge of STP effluent - chlorine	kg 1,4-DB eq	-4.33	-1.88	x	x
Avoided discharge of STP effluent - metals	kg 1,4-DB eq	-1.28	-0.61	x	x
Avoided discharge of STP effluent - organics	kg 1,4-DB eq	-0.04	-0.02	x	x
Avoided irrigation of STP effluent – chlorine	kg 1,4-DB eq	0.00	x	x	x
Avoided irrigation of STP effluent – metals	kg 1,4-DB eq	-0.01	x	x	x
Avoided irrigation of STP effluent - organics	kg 1,4-DB eq	0.00	x	x	x
Class A+ discharge to sea – chlorine	kg 1,4-DB eq	11.32	x	x	x
Class A+ discharge to sea – metals	kg 1,4-DB eq	0.24	x	x	x
Class A+ discharge to sea - organics	kg 1,4-DB eq	0.03	x	x	x
Class A+ irrigation – chlorine	kg 1,4-DB eq	0.00	x	x	x
Class A+ irrigation – metals	kg 1,4-DB eq	0.04	x	x	x
Class A+ irrigation - organics	kg 1,4-DB eq	0.00	x	x	x
AWTP product water (to dam) - metals	kg 1,4-DB eq	x	0.06	x	x
AWTP product water (to dam) - organics	kg 1,4-DB eq	x	0.00	x	x
AWTP RO reject (to sea) - chlorine	kg 1,4-DB eq	x	0.07	x	x
AWTP RO reject (to sea) - metals	kg 1,4-DB eq	x	0.45	x	x
AWTP RO reject (to sea) - organics	kg 1,4-DB eq	x	0.00	x	x
Sludge/biosolids - transport	kg 1,4-DB eq	0.01	0.01	x	x
Sludge/biosolids - land application	kg 1,4-DB eq	0.05	x	x	x
Power use	kg 1,4-DB eq	0.05	0.10	0.10	0.24
Chemicals manufacture	kg 1,4-DB eq	0.17	0.14	x	0.06
Chemicals transport	kg 1,4-DB eq	0.14	0.41	x	0.12
Other	kg 1,4-DB eq	0.02	0.07	0.15	0.04

Table 28: Breakdown of Freshwater Ecotoxicity Potential (FEP) results.

Process	Unit	Class A+	IPR	Rain Tank	Desal
Total	**kg 1,4-DB eq**	**0.15**	**0.17**	**0.01**	**0.05**
Avoided irrigation of STP effluent – chlorine	kg 1,4-DB eq	0.00	x	x	x
Avoided irrigation of STP effluent – metals	kg 1,4-DB eq	-0.02	x	x	x
Avoided irrigation of STP effluent - organics	kg 1,4-DB eq	-0.03	x	x	x
Class A+ irrigation (household) – chlorine	kg 1,4-DB eq	0.00	x	x	x
Class A+ irrigation (household) – metals	kg 1,4-DB eq	0.04	x	x	x
Class A+ irrigation (household) - organics	kg 1,4-DB eq	0.02	x	x	x
Class A+ irrigation (non residential) – chlorine	kg 1,4-DB eq	0.00	x	x	x
Class A+ irrigation (non residential) – metals	kg 1,4-DB eq	0.01	x	x	x
Class A+ irrigation (non residential) - organics	kg 1,4-DB eq	0.03	x	x	x
AWTP product water (to dam) - metals	kg 1,4-DB eq	x	0.05	x	x
AWTP product water (to dam) - organics	kg 1,4-DB eq	x	0.00	x	x
Sludge/biosolids - transport	kg 1,4-DB eq	0.00	0.00	x	x
Sludge/biosolids - land application	kg 1,4-DB eq	0.08	x	x	x
Power use	kg 1,4-DB eq	0.00	0.00	0.003	0.01
Chemicals manufacture	kg 1,4-DB eq	0.01	0.10	x	0.04
Chemicals transport	kg 1,4-DB eq	0.00	0.00	x	0.00
Other	kg 1,4-DB eq	0.02	0.02	0.004	0.00

Table 29: Breakdown of Terrestrial Ecotoxicity Potential (TEP) results.

Process	Unit	Class A+	IPR	Rain Tank	Desal
Total	**kg 1,4-DB eq**	**0.49**	**0.03**	**0.01**	**0.02**
Avoided irrigation of STP effluent – chlorine	kg 1,4-DB eq	0.00	x	x	x
Avoided irrigation of STP effluent – metals	kg 1,4-DB eq	-0.09	x	x	x
Avoided irrigation of STP effluent - organics	kg 1,4-DB eq	-0.05	x	x	x
Class A+ irrigation (household) – chlorine	kg 1,4-DB eq	0.00	x	x	x
Class A+ irrigation (household) – metals	kg 1,4-DB eq	0.13	x	x	x
Class A+ irrigation (household) - organics	kg 1,4-DB eq	0.03	x	x	x
Class A+ irrigation (non residential) – chlorine	kg 1,4-DB eq	0.00	x	x	x
Class A+ irrigation (non residential) – metals	kg 1,4-DB eq	0.04	x	x	x
Class A+ irrigation (non residential) - organics	kg 1,4-DB eq	0.05	x	x	x
Sludge/biosolids - transport	kg 1,4-DB eq	0.00	0.00	x	x
Sludge/biosolids - land application	kg 1,4-DB eq	0.28	x	x	x
Power use	kg 1,4-DB eq	0.00	0.01	0.007	0.02
Chemicals manufacture	kg 1,4-DB eq	0.02	0.02	x	0.00
Chemicals transport	kg 1,4-DB eq	0.00	0.00	x	0.00
Other	kg 1,4-DB eq	0.08	0.00	0.004	0.00

7.2.5 Global Warming Potential and Fossil Fuel Depletion

Figure 12 shows relatively large Global Warming Potential (GWP) and Fossil Fuel Depletion (FFD) for each of the four scenarios. Table 30 and Table 31 show that energy use is the major contributor to these results. The desalination scenario had substantially higher GWP and FFD burdens than for the other scenarios. The differences between the Rainwater Tank and two recycling based scenarios are marked, but much closer together.

While the rainwater tank energy use estimates for this study reflect the best available empirical data, it is likely that the statistical confidence in comparing the rainwater tank results to other scenarios would be low. The overall energy burden of rainwater tanks is dependent on a large range of design factors, including end-use type, pump type, backup system and the actual rainwater yield that is achieved. While the comparisons presented in this section are useful as an indication of relative magnitude, quantitative consideration of the uncertainty would improve the analysis.

Chemicals supply made smaller contributions to the overall GWP and FFD results, particularly for the two AWTP scenarios. For the IPR system, the biggest chemical contributor is the chemical flocculation step required for phosphorus and organics removal. The need for chemical phosphorus removal in the Class A+ scenario was lower than might normally be expected, because the default requirement for effluent discharge at the particular Pimpama location involved a low total phosphorus concentration. Instead, the main chemical culprit for the Class A+ system was the high level of sodium hypochlorite use for manganese oxidation and membrane cleaning. Product water remineralisation is the main cause of chemicals related GWP and FFD for the desalination scenario.

Table 30: Breakdown of Global Warming Potential (GWP) results.

Process	Unit	Class A+	IPR	Rain Tank	Desal
Total	**kg CO2 eq**	**1,305**	**2,396**	**2,015**	**4,415**
Power use	kg CO2 eq	971	1,824	1,883	4,301
Chemicals manufacture	kg CO2 eq	238	380	x	45
Chemicals transport	kg CO2 eq	40	115	x	33
Avoided discharge of wastewater - fugitives	kg CO2 eq	-0.8	0.3	x	x
STP fugitives (from N recycling)	kg CO2 eq	13	x	x	x
Class A+ irrigation - fugitives	kg CO2 eq	2.7	x	x	x
Sludge/biosolids to land - fugitives	kg CO2 eq	0.5	x	x	x
AWTP fugitives	kg CO2 eq	x	6	x	x
AWTP product water (to dam) - fugitives	kg CO2 eq	x	0.3	x	x
AWTP RO reject (to sea) - fugitives	kg CO2 eq	x	0.7	x	x
Other	kg CO2 eq	41	71	132	37

Table 31: Breakdown of Fossil Fuel Depletion (FFD) results.

Process	Unit	Class A+	IPR	Rain Tank	Desal
Total	**kg oil eq**	**305**	**584**	**548**	**1,078**
Power use	kg oil eq	237	445	460	1,051
Chemicals manufacture	kg oil eq	52	100	x	11
Chemicals transport	kg oil eq	6	17	x	5
Other	kg oil eq	9	22	89	12

7.3 Sensitivity Analysis

The results of Section 7.2 suggest that the Class A+ and rainwater tank results might be particularly sensitive to certain assumptions used in the inventory modelling. This concern was explored by modelling these two systems subject to a number of key variations.

7.3.1 Class A+ Recycling

Operational constraints mean that the Pimpama AWTP must process 100% of the secondary effluent regardless of the overall demand for Class A+ water. Given the low end-use assumptions underpinning this study, the Class A+ demand was low meaning a significant amount of Class A+ quality water being discharged to the sea.

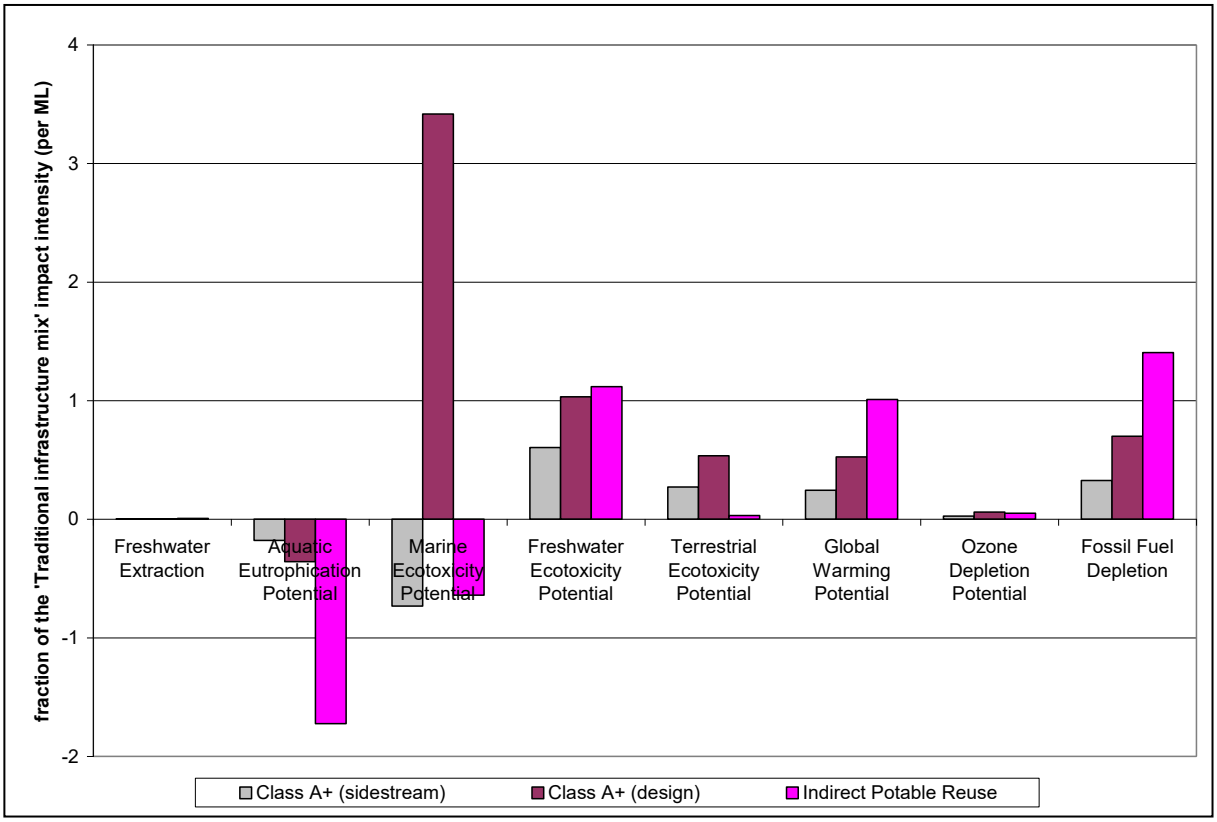

Figure 13: Alternative assumptions for the Class A+ scenario.

The results presented in Section 7.2 suggest that, for two key reasons, this will limit the benefits and magnify the downsides of the Class A+ recycling approach. Firstly, because the majority of the power and chemicals use is associated with the AWTP treatment steps, the associated impacts are independent of the system's ability to offset mains water use. Secondly, the high residual chlorine concentrations in the product water discharged to the sea negates any toxicity benefits from reducing secondary effluent discharge.

To explore the ramifications of these design constraints, results were generated for an alternative Class A+ scenario where the AWTP throughput is matched to the end-use demand. With this configuration, surplus secondary effluent would be discharged directly to the sea. Figure 13 compares the results for this alternative Class A+ scenario with the default Class A+ and IPR scenarios.

This illustrates that all the negative impacts associated with the extra treatment step are reduced substantially. Avoiding the marine discharge of highly chlorinated effluent also means that the net MEP benefit is comparable with that for the IPR recycling configuration. The only downside is the reduced AEP benefit because of the lower overall level of nutrient removal that is achieved.

7.3.2 Rainwater Tanks

As discussed in Section 5.1.1, the overall energy burden of rainwater tanks is dependent on a large range of design factors. There are three confounding issues that make it difficult to generate impact assessments with a high level of certainty. Firstly, legislated requirements for rainwater tank installation in SEQ allow significant freedom for differences in rainwater system configuration. Secondly, how tanks are actually being installed, configured and used in SEQ is not well understood. Thirdly, as the large scale rollout of household rainwater tanks will happen progressively over a number of years, there is significant scope for installation trends to change over time in response to external market forces.

Table 32: Alternative assumptions for rainwater tank system.

		Tank default assumptions	Alternative A	Alternative B
Backup arrangement		63% with auto bypass switch; 37% with trickle topup	100% with manual bypass switch	100% with trickle topup
Rainwater yield	**(kL/d)**	0.171	0.212	0.137
Induced irrigation^	**(kL/d)**	0.039	0	0.039
Pumping power	**(kWh/kL)**	1.2	0.8	2.5
Bypass switch power	**(kWh/d)**	0.041	0	0

^ quantity that does not offset mains water supply

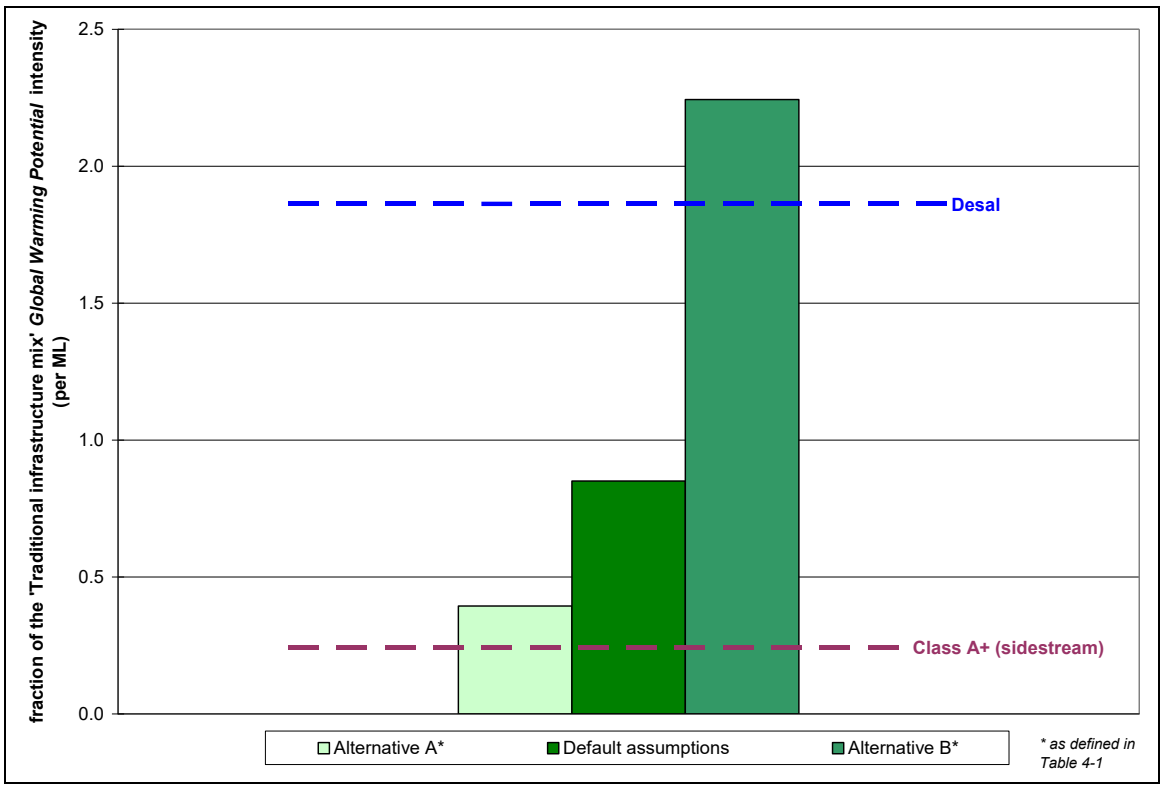

Figure 14: Sensitivity of the Rainwater Tank scenario to variation in key assumptions.

To explore the implications of different assumptions, results were generated for two alternative rainwater tank scenarios as described in Table 32. Scenario A is based on a configuration at the better end of the energy use spectrum: low pumping energy use, mains backup via a manually operated bypass, and a relatively high tank yield. Scenario B is based on a configuration likely to have a much higher energy burden: low tank yield therefore requiring a high degree of mains backup that is routed through the tank, combined with a relatively high energy delivery system.

Figure 14 compares the results for the default rainwater tank scenario with these two alternatives. Only the *Global Warming Potential* (GWP) results are provided, as GWP is a reasonable proxy for operational energy use and energy use is the primary cause of all the rainwater tank impacts considered in this chapter. The results are benchmarked against the desalination and Class A+ (using the 'sidestream' model discussed in Section 7.3.1) scenarios, as these involve the largest and smallest GWP results of the systems considered in this chapter.

Figure 14 shows that the GWP might vary from being nearly the lowest of the scenarios under consideration, to being higher than that for desalination. While these two alternative sets of rainwater tank assumptions were formulated for the sake of illustrating the potential variability, they do represent system configurations that are quite conceivable given current legislative requirements. They do not, however, span the extremes of what is possible or likely to occur over hundreds of thousands of individual rainwater tank systems.

7.4 Summary and Discussion

In the face of population growth, and with the need for water supply options that are less vulnerable to climate variability, choices are required on the best form of new water supply infrastructure to adopt. The environmental impacts of four alternative water supply systems were compared. These constitute the non-traditional water supply infrastructure adopted under the 'Future' scenario of this study.

For all four scenarios, the *Freshwater Extraction* (FWE) and *Ozone Depletion Potential* (ODP) results were negligible compared to the respective burdens associated with the overall Gold Coast urban water system. Across the other impact categories considered, a number of tradeoffs between the different approaches were apparent.

The two recycling systems delivered substantial net *Aquatic Eutrophication Potential* (AEP) benefits, particularly the IPR system which involved the greater level of AWTP nutrient removal. While direct reuse systems offer the advantage of reducing the overall volumetric discharge to waterways, this advantage was diminished by the low fraction of wastewater that was recycled under the Class A+ scenario for this case study. Nutrient losses from irrigated wastewaters did not greatly influence the results of this analysis, but their estimation requires assumptions that will be subject to great uncertainty. This issue warrants more careful consideration should this pathway represent a higher portion of the overall nutrient balance for other systems under consideration.

By changing the distribution of wastewater and associated pollutants, the two recycling systems also had major implications for the ecotoxicity results. The IPR system eliminates the discharge of secondary effluent and the associated chlorine and micropollutant residuals, delivering a substantial net reduction in *Marine Ecotoxicity Potential* (MEP). While the Class A+ system diverted a much smaller portion of wastewater from the sea, the manganese removal step eliminated a major source of MEP. Both systems redirect some of this toxicity burden to freshwater and/or terrestrial ecosystems. For the IPR system, this problem was minimised by the high level of micropollutant removal achieved by the AWTP. For the Class A+ system, wastewater irrigation and sludge disposal to agricultural soils generate comparatively large amounts of *Terrestrial* (TEP) and *Freshwater Ecotoxicity Potential* (FEP). Design constraints also meant that the high chlorine loading in surplus Class A+ product (discharged to the sea) delivered a net overall increase in MEP.

The benefits of water recycling come at the cost of high power and chemicals use. While both use membrane based treatment steps, the stricter water quality requirements for IPR meant this scenario involved much greater energy and chemicals use. Chemicals use in particular was responsible for notable contributions to the FEP and MEP, albeit incurred at various points of the supply chain outside the SEQ region. Such results should be interpreted cautiously, because of the reliance on database inventories that likely vary in quality across the different chemicals.

The ecotoxicity results from the direct pathways are also subject to large uncertainties, because of the difficulty in predicting effluent pollutant loads and the removal pathways involved in the advanced wastewater treatment processes. Compounding these data quality issues are the inherent uncertainties involved in the chemical toxicity models used in LCA (see Section 4.5.4). A small number of contaminants (chlorine and only a few metals) dominate the ecotoxicity results, and the findings are therefore extremely sensitive to the precision of the inventory and impact models used.

Power and chemicals use were the two main causes of *Global Warming Potential* (GWP) and *Fossil Fuel Depletion* (FFD) for the two recycling systems, with the IPR scenario having the greater impacts in both cases. Furthermore, the Class A+ results reported here are somewhat elevated by design constraints requiring that all secondary effluent is treated to Class A+ standard even though the majority was discharged directly to the sea because of low demand assumptions. When this constraint was removed, the energy/chemicals related impacts of the Class A+ scenario were greatly reduced. This also meant the Class A+ system delivered a net MEP benefit because the excessive chlorine discharge was avoided. This highlights the sensitivity of direct reuse systems to supply-demand mismatches. If AWTP throughput can be tailored to meet changing demands, then the downsides of over treatment can be avoided. Maximising demand would have similar implications, with the added benefit of further reducing the discharge of nutrients to waterways.

GWP and FFD were the most significant impacts for the rainwater tank and desalination scenarios. Power use was the main contributor to these results, and for these two impact categories the main point of difference between the four systems under consideration. Even with the design constraints involved, the Class A+ system demonstrated the lowest GWP and FFD. The GWP and FFD for desalination were notably higher than for all other scenarios. The IPR and rainwater tank results fell somewhere in between. However, rainwater tank power use was shown to be extremely sensitive to the choice of assumptions, with the GWP possibilities spanning the lowest and highest of the results for the other scenarios. In terms of forecasting long term energy burdens of rainwater tanks, this suggests both risks (should market trends deviate towards high energy installations) and opportunities (if legislative or market signals could encourage the installation of more energy efficient configurations).

The quantitative analytical approach presented here clearly delivers a more comprehensive consideration of environmental tradeoffs than is often the case in water supply planning processes. However the tradeoffs analysis is clouded to some extent by uncertainties in key areas. The quality of this assessment would be improved by greater data availability, a better understanding of the uncertainties involved, and recommendations on default assumptions where empirical data is not available. In addition, the results of this study demonstrate the need for scenarios to be tested against varying water end-use assumptions where the systems under consideration (e.g. rainwater tanks; direct wastewater reuse systems) are potentially demand constrained.

8. SUMMARY – FINDINGS AND RECOMMENDATIONS

This study uses quantitative Life Cycle Assessment (LCA) to analyse and compare the Gold Coast urban water system with/without the inclusion of a number of alternative water supply technologies. While this study was focussed on the Gold Coast area, it has been scoped and presented in a manner that can inform debate on the range of water supply options being contemplated across South East Queensland (SEQ).

The five research objectives of this study were to provide information and guidance on:

1. the greenhouse gas risk profile of urban water system infrastructure;
2. the spread of environmental impacts associated with urban water system infrastructure, and opportunities to reduce these impacts;
3. environmental tradeoffs involved in choosing between alternative water supply options;
4. metrics available for including a broad range of environmental issues into quantitative analysis of urban water systems; and
5. key data gaps that should be priorities for more detailed research.

To do this, the following two scenarios were considered:

- *'Traditional infrastructure mix'*: A conventional, linear urban water system dominated by mains supply from local dams, and the discharge of secondary treated sewage to waterways.
- *'Future infrastructure mix'*: A system that caters for substantial population growth by supplementing the conventional technologies with four additional water supply approaches: seawater desalination; large scale adoption of household rainwater tanks; direct recycling of Class A+ water; and an indirect potable reuse scheme utilising the existing local dams.

Research Objective 1

Quantify the Greenhouse Gas risk profile for key components of the SEQ urban water system.

Overall Urban Water System

- Power use across the system is the biggest contributor to the greenhouse gas footprint of the Gold Coast urban water infrastructure. For a traditional infrastructure mix relying on local dam supplies for mains water supply, power use was responsible for ~50% of total greenhouse gas emissions.
- The inclusion of more energy intensive alternative water supply technologies meant a 1.6× increase in the greenhouse gas intensity (on a per capita basis) of the overall water cycle. As a result, power use represented ~70% of total greenhouse gas emissions for a scenario that included urban water supply from desalination, recycling and large numbers of rainwater tanks.
- Even with a seawater desalination contribution to urban water supply larger than might be expected over the whole of SEQ, the wastewater treatment system still accounted for ~30% of total power use. The Gold Coast has relatively high sewage and treated wastewater pumping requirements, and only a small amount of anaerobic digestion energy recovery. Nonetheless, debates on the energy use of the SEQ urban water system should not overlook the contribution associated with wastewater treatment.

- Energy use should not be seen as a proxy for the overall greenhouse gas footprint of the SEQ urban water system. Fugitive greenhouse gas emissions contributed 29% of the total for the traditional dam-based urban water system. N_2O (15%) was the most important fugitive gas associated with wastewater treatment, although CH_4 (5%) and non-biogenic CO_2 (2%) also made notable contributions. While the sewer network and STPs are the biggest emission points for these gases, there are also substantial emissions associated with biosolids reuse. CH_4 generated from ongoing carbon inflows to the Gold Coast dams was the other important source (7%) of fugitive greenhouse gases.
- When the more energy intensive water supply technologies were included, the overall contribution from fugitive gases decreased to 16%. However, predictions of fugitive N_2O, CH_4 and non-biogenic CO_2 emissions are constrained by limitations of both data and fundamental knowledge, and are therefore subject to considerable uncertainty. Given the rapid evolution of greenhouse gas science and reporting worldwide, fugitive emissions may represent a considerable future exposure risk for urban water utility managers. Continuation of initiatives to improve understanding in this regard would enhance the capacity to manage this risk.
- Even with the inclusion of energy-intensive water supply options, the overall greenhouse gas contribution associated with secondary-level wastewater treatment is greater than 40% of the total. Improving the operations and/or design of wastewater systems might therefore offer the potential to substantially reduce the overall greenhouse gas burden of the urban water system.
- The manufacture and supply of treatment chemicals makes a smaller but notable contribution (7% of total under the traditional infrastructure scenario) to the overall greenhouse gas footprint. The equivalent contribution from the manufacture and installation of infrastructure materials was 12%. Under current Australian reporting systems, water utilities are not required to account for the indirect emissions associated with these activities. However, the alternative water supply systems under consideration in SEQ are more chemicals and materials intensive and the emissions associated with these pathways are likely to increase as these technologies are adopted. This might represent another important point of exposure to the introduction of an Australian carbon pricing regime.

Alternative Water Supply Technologies

- For the four alternative water supply options considered in this study (seawater desalination; Class A+ recycling; indirect potable reuse; rainwater tanks), power use was the dominant source of greenhouse gas emissions. The only exception of note was for the two recycling systems, where chemicals use represented 15-20% of their greenhouse gas footprint.
- While predictions of the treatment energy required for seawater desalination or water recycling are reasonably robust, this is not the case for household scale rainwater tanks. The overall energy burden of rainwater tanks is dependent on a large number of design and operational parameters, and the small amount of available data suggests that extremely large variability is possible.
- Because rainwater tanks will be installed progressively over the next 40 years, their long-term energy burden is hard to predict given the potential for market forces to change during that time. While this might represent an important risk for the urban water sector, it also provides an opportunity to avoid a substantial source of greenhouse gas emissions if appropriate constraints on tank system design could be introduced. Further research into the causative factors of rainwater tank energy use, and the significance of the associated uncertainties, may help guide policies to minimise the long term rainwater tank energy burden.

Research Objective 2

Identify the full suite of environmental and resource use impacts associated with the life-cycle of existing or planned water system infrastructure at the Gold Coast; and identify key opportunities to reduce these impacts.

Overall Urban Water System

- *Freshwater Extraction* (FWE), *Aquatic Eutrophication Potential* (AEP), *Ecotoxicity Potential*, *Global Warming Potential* (GWP), *Ozone Depletion Potential* (ODP), *Fossil Fuel Depletion* (FFD), and *Human Toxicity Potential* (HTP) across the life-cycle of urban water system infrastructure were assessed. Urban water system operations dominated the impacts in all cases other than for HTP. The system boundary for this study excluded potentially large sources of HTP directly related to urban water system operations.
- Wastewater management (collection, treatment and discharge) was responsible for the major contributions to all impact categories other than FWE and HTP. Improving the operations and/or design of wastewater systems might therefore offer the potential to substantially reduce the overall environmental burden of the urban water system. Debates on the environmental implications of urban water system planning decisions should focus on more than just the choice between water supply alternatives.
- The adoption of non-traditional water supply technologies delivered reductions in the per-capita FWE and AEP, but increased the relevance of most other impact categories when benchmarked against the broader Australian economy. This suggests that future pressures for environmental mitigation by the urban water sector are likely to be spread across a wider range of issues than has traditionally been the case. It also confirms that greenhouse gas emissions are not an adequate proxy for the range of important environmental externalities associated with urban water system operations.
- While this analysis was based specifically on the Gold Coast region, the choice of infrastructure types is representative of the range under consideration across SEQ. Changing the spatial boundary would change the relative mix of infrastructure types, but is unlikely to introduce fundamentally different issues for consideration. The results and interpretation are therefore likely to be informative from the broader SEQ perspective.

Major Impact Contributions

- The "embedded" water in power or materials used by the urban water system is minor compared to the freshwater extraction required for urban mains water supply. This study did not consider the ecological significance of shifting the point of hydrological intervention from dam extractions to rainwater tank interception.
- Secondary effluent nutrient discharges are the main cause of *Aquatic Eutrophication Potential* (AEP). Recycling schemes can therefore deliver substantial reductions in AEP if they incorporate additional nutrient removal and/or divert wastewater streams for direct household or non-residential reuse.
- The biosolids disposal pathway is a major sink for sewage nutrients. Agricultural biosolids reuse could be a substantial source of AEP if it results in nutrient flux to nearby streams without offsetting equivalent losses from synthetic fertiliser use. Quantitatively predicting the implications of biosolids reuse on fertiliser management and nutrient fluxes is extremely uncertain and likely to be very case-specific. Guidance on best practice approaches to undertaking this task might enhance the capacity for water planners to assess biosolids options.
- Biosolids metals were the dominant source of *Terrestrial Ecotoxicity Potential* (TEP) and *Freshwater Ecotoxicity Potential* (FEP) in this study, while residual chlorine and metals in wastewater were the biggest cause of *Marine Ecotoxicity Potential* (MEP). Organic micropollutants played only a minor role in the ecotoxicity results. This finding should be

treated cautiously, as ecotoxicity impact factors existed for only a very small portion of the organic micropollutants that might be present in urban wastewater streams. Furthermore, there are concerns that LCA toxicity models might overstate the importance of metals and chlorine (see Research Objective 4). Nonetheless, the results do highlight the potential merits of reducing the level of contaminants in wastewater and biosolids discharges to the environment. Large contributions to MEP and FEP were also associated with the transport of biosolids, supply (manufacture and transport) of chemicals, and generation of power.

- The findings for Research Objective 1 identify the key causes and opportunities associated with *Global Warming Potential* for urban water supply and wastewater systems. They are also relevant to *Fossil Fuel Depletion* (FFD), as the FFD results in this study were dominated by power use.
- The *Ozone Depletion Potential* (ODP) of urban water systems is likely to be dominated by fugitive N_2O emissions from the wastewater system, and make a relatively significant contribution to Australia's total ODP. STP denitrification processes and the soil application of biosolids nitrogen are likely to be the greatest sources of N_2O generation. Predicting N_2O emission rates from the range of potential generation/emission points in the wastewater cycle is extremely uncertain. Further investigation is warranted into both the fundamental drivers for N_2O generation; and into the most appropriate assumptions for use in water system planning.
- Pipe manufacture and coal-fired power generation dominated the *Human Toxicity Potential* (HTP) results in this study. This suggests benefits in adopting technologies with low materials and power use intensity. However, the findings for Research Objective 4 identify a number of issues that must be addressed before the relative HTP significance of direct operational issues can be ascertained.

Prioritising the Contributions

- Ranking the opportunities to reduce environmental impacts is a function of the institutional priorities of urban water managers, and these were not identified in this study. However the analysis did identify that the biggest individual contributions of the urban water system to the overall Australian environmental burden are likely to be freshwater use, wastewater nutrient discharges, fugitive N_2O emissions, and the wastewater/biosolids discharge of chlorine, metals and organic contaminants.

Research Objective 3

Identify the key environmental tradeoffs involved in decisions between alternate approaches to supplying water to the growing SEQ population.

Desalination

- Of the four systems considered, sea water desalination incurred the greatest *Global Warming Potential* and *Fossil Fuel Depletion* because of its substantial power use. Power use was the main source of desalination-related impacts considered in this study. Desalination chemicals use was much less than for the two recycling systems considered, but still incurred small ecotoxicity impacts through the chemicals supply chain. Possible ecological implications of high concentration brine discharge were not included in this study.

Rainwater Tanks

- For the set of impact categories considered in this study, operational energy use was the primary cause of environmental impacts associated with rainwater tanks. However the potential for household stormwater detention to have positive or negative implications on downstream receiving waters was not considered.

- For household rainwater tanks installed to provide toilet, laundry and external end-uses, best estimates for their configuration and performance resulted in *Global Warming Potential* and *Fossil Fuel Depletion* results of similar magnitude to those for the two recycling systems under consideration. However, predictions of rainwater tank energy use should be considered highly uncertain given the potential for large variation in key configuration parameters.

Water Recycling

- The *Global Warming Potential* and *Fossil Fuel Depletion* implications of offsetting mains water use with a Class A+ direct reuse system were substantially elevated by the requirement that all secondary effluent be treated to Class A+ standard, in combination with the assumption of low Class A+ demand used for this study. Despite this, Class A+ recycling had the lowest *Global Warming Potential* and *Fossil Fuel Depletion* results of the four systems under consideration.
- The nutrient discharge reductions achieved by the Class A+ recycling system were constrained by the assumption of low Class A+ demand.
- The Class A+ reuse system incurred potentially significant marine, freshwater and terrestrial ecotoxicity impacts. These were reduced substantially when the system was modelled with the AWTP throughput limited to the actual demand level. Avoiding the discharge of highly chlorinated product water to the sea would mean the Class A+ system delivers a net benefit in terms of *Marine Ecotoxicity Potential*, primarily because of the Manganese removal step involved in the treatment chain.
- By utilising the existing mains supply network, the IPR system maximises the potential for reuse and avoids the supply-demand challenges associated with direct reuse systems. The IPR system showed the most substantial benefits in terms of *Aquatic Eutrophication Potential*, because of the assumption that the AWTP treatment process would deliver substantial nutrient removal. However, it's relatively high power and chemicals usage meant that the IPR system had worse results than the optimised Class A+ scenario for most other impact categories.
- The results of this study suggest that both the recycling systems will transfer some of the ecotoxicity risk from the marine to freshwater and terrestrial environments. Ascertaining the significance of this trade-off is complicated by the limited available data on contaminant concentrations, and by question marks over the local relevance of the LCA toxicity models. Constraints in the available LCA toxicity models also meant that the human health implications of recycling tertiary treated wastewater into drinking water supplies were not adequately considered in this study.

General

- LCA does not account for microbiological risks, and no consideration was given to the microbiological health implications of Class A+ cross connections, rainwater tank use for drinking water, or other possible contamination pathways.
- The *Ozone Depletion Potential* (associated with power use and denitrification) of all four systems was negligible compared to that associated with the treatment of urban sewage.
- Incorporating this mix of alternative water supply approaches into the infrastructure mix reduced the *Freshwater Extraction* and *Aquatic Eutrophication Potential* intensity of the urban water system. However this came at the cost of substantially increased power use, *Global Warming Potential* and *Fossil Fuel Depletion*. Changes to the ecotoxicity profiles were less substantial, given the relatively small portion of wastewater that was recycled in this study.
- The environmental implications of direct reuse systems and household scale rainwater tanks can be sensitive to water supply-demand imbalances because of their direct coupling with specific household end-uses. Where such systems are under consideration, quantitative comparisons of urban water supply alternatives should include sensitivity testing for different end-use demand levels.

Research Objective 4

Identify environmental metrics available for quantitative multi-criteria analysis of different urban water cycle options.

Choice of Indicators to Support Decision Making

- Nine Life Cycle Impact Assessment (LCIA) indicators were used for this study, each proving directly relevant to urban water systems. In a number of cases, methodological improvements to the associated impact models would provide results that are more informative to decision makers. Further detail on these opportunities is provided below. In the interim, consideration of the following indicators, using the default models described in this report, would provide a sound basis for broad spectrum quantitative environmental comparisons of urban water system options:
  - Freshwater Extraction
  - Aquatic Eutrophication Potential
  - Marine, Freshwater and Terrestrial Ecotoxicity Potential
  - Global Warming Potential
  - Ozone Depletion Potential
  - Fossil Fuel Depletion
  - Human Toxicity Potential
- For SEQ urban water systems, the majority of *Freshwater Extraction, Aquatic Eutrophication Potential* and *Ecotoxicity Potential* (MEP, FEP and TEP) will be associated with local environments, and these issues should be a focus of urban water system planning. Because of their global nature, the relevant LCIA models should not be seen as a substitute for more detailed local modelling and/or risk assessment in the decision making process. However, they can provide simple but robust quantitative assessments for situations where detailed modelling is not possible, such as during the initial screening step of an options selection process. The *Human Toxicity Potential* indicator may offer similar value, pending resolution of a number of constraints with the model used for this study.
- Further review is required into whether there are more appropriate metrics for including local toxicity assessment into multi-criteria decision making. Any such review should note one particular advantage of the LCIA toxicity models, in that they provide a global perspective on the relative importance of the local toxicity issues. This can offer a useful insight to decision makers looking to prioritise tradeoffs across a large range of quantitative indicators.
- The recommended indicators for *Global Warming Potential*, *Ozone Depletion Potential* and *Fossil Fuel Depletion* provide a best practice means for including these issues in analysis of urban water systems. Subject to any recommendations noted below, the impact models used in this study should be included in any options comparison where these issues are considered relevant.
- An assessment of *Minerals Depletion (MD)* was not part of this study, but should be included in future analysis. The urban water system plays a significant role in global phosphorus flows, and a suitable *MD* indicator would provide perspective on wastewater phosphorus recovery in terms of broader resource depletion issues. The available LCIA models do not account for phosphorus resources in this way, and this should be a priority for methodological development.
- The Gold Coast, and possibly other areas of SEQ, involves substantial irrigation of treated wastewaters. This study gave no consideration to any risks of soil degradation that might result from elevated salinity levels in the wastewater. If this issue is worthy of inclusion in quantitative options analysis, then the LCIA indicator for soil salinisation proposed by Feitz *et al.* (2002) should be taken into consideration.

- The LCIA literature contains numerous other impact categories that were not considered in this study on the expectation that they were unlikely to be of relevance for urban water systems. This assumption was not tested quantitatively. Doing so may help guide SEQ water cycle planners in the best way to incorporate LCA and LCIA into the decision making process.

Putting the Impact Results into Perspective

- In order to generate perspective on the relative significance of different environmental issues, LCIA results are typically normalised against national or global estimates of total impact potential. This normalisation approach delivered valuable insights into the nature and significance of the LCIA results in this study. However, the best available Australian LCIA datasets involve substantial data gaps, and caution must be taken in the interpretation of results normalised in this way.
- If the normalisation step is required for incorporation of LCIA indicators into urban water systems planning, then further review of normalisation approaches should be undertaken. Where possible, improvements should be made to the Australian normalisation dataset generated by this study. Pending input on the specific perspectives of interest to water system decision makers, consideration should also be given to whether alternative benchmarks might also be relevant.

Use of the Individual Impact Models

- Assessing the potential environmental impacts arising from hydrological interventions is made difficult by the complex nature of the cause-effect relationships involved. This study adopted the simple (and common) measure of total *Freshwater Extraction* as a proxy for pressure on the relevant ecosystems. Further investigation is required into whether recent proposals to incorporate a measure of abundance would enhance comparisons that involve significant levels of extraction from different catchments within SEQ. Where appropriate to specific case studies, consideration should also be given as to how best compare extractions from major water supply dams with substantial levels of direct small scale creek extraction.
- The suite of recommended LCIA indicators do not account for any environmental implications (whether positive or negative) from the urban stormwater retention achieved by rainwater tanks. Further investigation into this issue is warranted; given domestic rainwater tanks are likely to become a major contributor to the overall water supply balance in SEQ, and growing local interest in the use of development scale urban stormwater reuse.
- A generalised *Aquatic Eutrophication Potential (AEP)* model was used for this analysis, in order to provide results that are informative from the broader SEQ perspective. However, more focussed choice of *AEP* impact models would be warranted for case study-specific decision making in SEQ. A number of priorities for improvement to the *AEP* model were identified:
  - Estimates of the nutrient losses (to waterways) from biosolids and wastewater reuse should be tailored to specific case studies. Further investigation is required into whether a set of default values and corresponding application criteria could be provided to inform this process.
  - Criteria should be developed to guide the appropriate choice (if any) of rate limiting nutrients for various receiving waterways. An alternative might be to develop waterway specific *AEP* models for SEQ. This task should then reconsider the case for using separate *Marine AEP* and *Freshwater AEP* indicators.
  - Both primary oxidation, and airborne nitrogen emissions, made relatively minor contributions to the results of this study. While this remains the case, these issues should remain a part of LCIA eutrophication models pending the ongoing debate in the LCIA community on whether and how best to do so. Closer scrutiny of the underpinning *AEP* model assumptions would be required if either of these issues were to be significant to the results of a particular case study.

- If LCA based toxicity assessment is to be adopted, then the models provided by this study offer the most relevant and comprehensive publicly available set of indicators. However, there are a number of methodological improvements that would enhance their usefulness, and these are briefly summarised in the following list.
  - Improve the assessment of organic micropollutants by: (a) extending the suite of toxicity impact factors available; and/or (b) incorporating whole-of-effluent toxicity results into the LCA toxicity framework.
  - Review whether the incorporation of whole-of-effluent toxicity testing might provide a suitable mechanism for the consideration of RO concentrate (brine) ecotoxicity.
  - Review the suitability of available toxicity impact factors for metals emissions, in particular with respect to (a) wastewater metals speciation; and (b) the prospect that biosolids metals pose relatively low ecotoxicological risks to Australian soils.
  - Critique the toxicological relevance of the relatively large impact factors associated with wastewater chlorine emissions.
  - Extend the inventory data and toxicity models to better incorporate the human health implications of water supply from conventional WTPs, rainwater tanks, and indirect potable reuse.
  - Modify the full suite of toxicity impact factors to reflect the significant geographical differences between Australia and the Europe-centric assumptions that underpin the factors provided by this study.
  - Improve the inventory data in a number of key areas that could underpin default assumptions for use by urban water planners - particularly the organic micropollutant concentrations in wastewater and biosolids; materials use in infrastructure construction; and the second order inventories associated with chemicals and power supply.
- Power generation makes a major contribution to the *Global Warming Potential* of urban water systems, assuming that coal-fired power generation features prominently in the long-term marginal power supply mix. The appropriate choice of marginal power generation technologies is an area of growing debate in the LCA community. Given the long term nature of infrastructure decisions in the urban water sector, the sensitivity of decision making to alternative marginal power supplies should be considered. Further investigation into this issue would provide guidance to the SEQ urban water sector on the appropriate choices for environmental analysis to support decision making.
- It is likely that there will be a growing debate on how best to characterise the *Ozone Depletion Potential* of N_2O emissions, and possibly even that for CH_4 and CO_2 emissions. Given the significance of these three gases to urban water system inventories, SEQ urban water planners should continue to review the outcomes from this debate. In the meantime, the model developed for this study includes N_2O emissions and should be used for any future analysis.
- Once a *Minerals Depletion* indicator is made available, consideration should be given to combining fossil fuels and minerals into a single indicator that characterises the implications of long term resource depletion. The ReCiPe method uses a marginal supply cost approach to doing this integration step, but the LCIA community has not reached a consensus on whether this is the most appropriate approach for expressing the sustainability implications. Further investigation into the relative merits of the alternative approaches is warranted.

APPENDIX A Simapro Inputs

Water Treatment Plants

Molendinar WTP

Group	Parameter	Units	Default value	Uncertainty distribution parameters							Source
				lognormal		triangle			uniform		
				geometric mean	geometric SD	min	most likely	max	min	max	
Raw water	pumping power	[kWh/ML]	113	113	1.06						Default value calibrated to GCW data. Variance informed by equivalent values for other pumping systems.
WTP power use	flow specific	[kWh/ML]	37.7	37.7	1.03						Total WTP power use from GCW - assumed that 70% is flow dependent to calculate default value. Variance informed by analysis of desalination plant data.
	Fixed	[MWh/d]	1.6								Total WTP power use from GCW - assumed that 30% is fixed (time dependent).
Chemicals use	Lime use	[kg/ML]	27	27.3	1.1						Default value calibrated to GCW data. Variance informed by equivalent values for other treatment systems.
	CO2 use	[kg/ML]	23	22.7	1.1						" " "
	Alum Sulphate use	[kg/ML]	55	55.3	1.1						" " "
	Poly (dry) use	[kg/ML]	0	0.055	1.1						" " "
	Poly (liquid) use	[kg/ML]	2	1.93	1.1						" " "
	Caustic use	[kg/ML]	24	23.8	1.1						" " "
	Sodium Hypochlorite use	[kg/ML]	40	40.2	1.1						" " "
	Potassium Permanganate use	[kg/ML]	0	0.263	1.1						" " "
	Activated Carbon use	[kg/ML]	7	6.9	1.1						" " "
Product water	Recovery	[ML-product / ML-feed]	0.995								Gold Coast Water
	Flow	[ML/d]	98.4								Gold Coast Water
Sludge	Solids generation	[t-ws/ML]	0	0.051	1.1						Default value calibrated to GCW data.

Mudgeeraba WTP

Group	Parameter	Units	Default value	Uncertainty distribution parameters							Source
				lognormal		triangle			uniform		
				geometric mean	geometric SD	min	most likely	max	min	max	
Raw water	pumping power	[kWh/ML]	113	113	1.06						Default value calibrated to GCW data. Variance informed by equivalent values for other pumping systems.
WTP power use	flow specific	[kWh/ML]	22.5	22.5	1.03						Total WTP power use from GCW - assumed that 70% is flow dependent to calculate default value. Variance informed by analysis of desalination plant data.
	Fixed	[MWh/d]	0.5								Total WTP power use from GCW - assumed that 30% is fixed (time dependent).
Chemicals use	Lime use	[kg/ML]	20	19.5	1.1						Default value calibrated to GCW data. Variance informed by equivalent values for other treatment systems.
	CO2 use	[kg/ML]	31	30.9	1.1						" " "
	Alum Sulphate use	[kg/ML]	68	67.9	1.1						" " "
	Caustic use	[kg/ML]	33	33.2	1.1						" " "
	Sodium Hypochlorite use	[kg/ML]	46	45.6	1.1						" " "
	Potassium Permanganate use	[kg/ML]	1	0.5	1.1						" " "
Product water	Recovery	[ML-product / ML-feed]	0.984								Gold Coast Water
	Flow	[ML/d]	47.6								Gold Coast Water
Sludge	Solids generation	[t-ws/ML]	0	0.132	1.1						Default value calibrated to GCW data.

Group	Parameter	Units	Default value	Uncertainty distribution type	Uncertainty distribution parameters							Source
					lognormal		triangle			uniform		
					geometric mean	geometric SD	min	most likely	max	min	max	
STP	connected EP	[p]	55,660									Gold Coast Water
Raw sewage	Flow	[ML/d]	9.8									Gold Coast Water
	COD	[kg/d]	7,621	Lognormal	7,621	1.30						Default value from GCW. Variance informed by analysis of STPs undertaken by de Haas et al (2009)
	C:COD ratio	[mg-C/mg-COD]	0.3									Following the modelling approach of de Haas et al (2009)
	non-biogenic carbon fraction	[w/w]	0.1	Triangle			0.01	0.1	0.25			Max value taken from Griffith et al (2009). Min & ML values chosen to explore wide possible range.
	TKN	[kg/d]	819	Lognormal	819	1.27						Default value from GCW. Variance informed by analysis of STPs undertaken by de Haas et al (2009)
	TP	[kg/d]	157	Lognormal	157	1.26						Default value from GCW. Variance informed by analysis of STPs undertaken by de Haas et al (2009)
	dissolved CH4 concentration	[mg/l]	5	Triangle			1	5	30			Default and range taken from Guisasola et al (2008, 2009)
STP chemicals use	Ethanol use	[kg/d]	81	Lognormal	81	1.2						Calibrated to data from Gold Coast Water
	Poly (liquid) use	[g/kg-COD]	4									Calibrated to data from Gold Coast Water
	Poly (dry) use	[g/kg-COD]	0.79									Calibrated to data from Gold Coast Water
STP power	power use	[kWh/d]	6063	Lognormal	6063	1.18						Default calibrated to data from GCW. Variance informed by analysis of STPs undertaken by de Haas et al (2009)
STP power generation	power generation	[kWh/ML]	0									Calibrated to data from Gold Coast Water
	unoxidised CH4 fraction	[w/w]	0.00335									Following the modelling approach of de Haas et al (2009)
	NOx generation	[kg-NOx/ML]	0									Based on similar treatment systems modelled by Foley et al (2010a)
	SOx generation	[kg-NOx/ML]	0									Based on similar treatment systems modelled by Foley et al (2010a)
	CO generation	[kg-NOx/ML]	0									Based on similar treatment systems modelled by Foley et al (2010a)
STP fugitives	NH3 generation (overall)	[kg-NH3/kg-TN]	0.0006									Based on similar treatment systems modelled by Foley et al (2010a)
	N2O generation (overall)	[kg-N2O/kg-dN]	0.021	Lognormal	0.021	1.95						Geometric mean & geometric SD values calculated from the full dataset collected by Foley et al (2010b).
	CH4 generation (2° treatment)	[kg-CH4/d]	0									Based on similar treatment systems modelled by Foley et al (2010a)
Grit & screenings	grit generation	[g/EP/d]	7.19									Calibrated to data from Gold Coast Water
	transport distance	[km]	10	Triangle			5	10	35			Default value from GCW.
	landfill gases	[kg-CO2e/kg]	1.11									Following the modelling approach of de Haas et al (2009)
STP biological sludge	Solids generation	[kg-ds/kg-CODin]	0.557									Calibrated to data from Gold Coast Water
	P removal	[g-dP/kg-TCOD]	14.59									Calibrated to data from Gold Coast Water
	C concentration	[w/w-ds]	0.333									Following the modelling approach of de Haas et al (2009)
	N concentration	[kg-N/kg-ds]	0.075									Following the modelling approach of de Haas et al (2009)
STP chemical sludge	Solids generation	[kg-ds/kg-FeClx]	0.602									Calibrated to data from Gold Coast Water
Biosolids	transport distance	[km]	200	Triangle			60	200	300			Default value based on transport to Darling Downs. Min & max values chosen to explore wide possible range.
	moisture content	[w/w]	0.874									Gold Coast Water
Effluent	pumping power use	[kWh/ML]	47	Lognormal	47	1.10						Default calibrated to data from GCW.
	reuse %	[v/v]	0.196	Triangle			0.15	0.196	0.25			Default value set equal to average (provided by Gold Coast Water) for all GC STPs. Assumed this might vary ±25% over the long term.
	NH4 concentration	[mg-N/l]	0.43	Lognormal	0.4	1.30						Default value from GCW. Variance informed by analysis of STPs undertaken by de Haas et al (2009)
	NOx concentration	[mg/l]	0.68	Lognormal	0.7	1.30						" " " " " "
	DON concentration	[mg/l]	0.75	Lognormal	0.8	1.30						" " " " " "
	PN concentration	[mg/l]	0.5	Lognormal	0.5	1.30						" " " " " "
	DP concentration	[mg/l]	0.59	Lognormal	0.6	1.30						" " " " " "
	PP concentration	[mg/l]	0.23	Lognormal	0.2	1.30						" " " " " "
	COD concentration	[mg/l]	35.00	Lognormal	35.0	1.20						" " " " " "
	C:COD ratio	[mg C/mg COD]	0.37									Following the modelling approach of de Haas et al (2009)
	TSS concentration	[mg/l]	7.00	Lognormal	7.0	1.30						Default value from GCW. Variance informed by analysis of STPs undertaken by de Haas et al (2009)
	free chlorine	[mg/L]	0.000									" " " " " "
	monochloramine	[mg/L]	0.000									" " " " " "

Group	Parameter	Units	Default value	Uncertainty distribution type	Uncertainty distribution parameters							Source
					lognormal		triangle			uniform		
					geometric mean	geometric SD	min	most likely	max	min	max	
STP	connected EP	[p]	290,338									Gold Coast Water
Raw sewage	Flow	[ML/d]	54									Gold Coast Water
	COD	[kg/d]	36,067	Lognormal	36,067	1.30						Default value from GCW. Variance informed by analysis of STPs undertaken by de Haas et al (2009)
	C:COD ratio	[mg-C/mg-COD]	0.3									Following the modelling approach of de Haas et al (2009)
	non-biogenic carbon fraction	[w/w]	0.1	Triangle			0.01	0.1	0.25			Max value taken from Griffith et al (2009). Min & ML values chosen to explore wide possible range.
	TKN	[kg/d]	3,333	Lognormal	3,333	1.27						Default value from GCW. Variance informed by analysis of STPs undertaken by de Haas et al (2009)
	TP	[kg/d]	724	Lognormal	724	1.26						Default value from GCW. Variance informed by analysis of STPs undertaken by de Haas et al (2009)
	dissolved CH4 concentration	[mg/l]	5	Triangle			1	5	30			Default and range taken from Guisasola et al (2008, 2009)
STP chems use	Poly (dry) use	[g/kg-COD]	1.64									Calibrated to data from Gold Coast Water
STP power	power use	[kWh/d]	33357	Lognormal	33357	1.18						Default calibrated to data from GCW. Variance informed by analysis of STPs undertaken by de Haas et al (2009)
STP power generation	power generation	[kWh/ML]	0									Calibrated to data from Gold Coast Water
	unoxidised CH4 fraction	[w/w]	0.00335									Following the modelling approach of de Haas et al (2009)
	NOx generation	[kg-NOx/ML]	0									Based on similar treatment systems modelled by Foley et al (2010a)
	SOx generation	[kg-NOx/ML]	0									Based on similar treatment systems modelled by Foley et al (2010a)
	CO generation	[kg-NOx/ML]	0									Based on similar treatment systems modelled by Foley et al (2010a)
STP fugitives	NH3 generation (overall)	[kg-NH3/kg-TN]	0.001									Based on similar treatment systems modelled by Foley et al (2010a)
	N2O generation (overall)	[kg-N2O/kg-dN]	0.021	Lognormal	0.021	1.95						Geometric mean & geometric SD values calculated from the full dataset collected by Foley et al (2010b).
	CH4 generation (2° treatment)	[kg-CH4/d]	0									Based on similar treatment systems modelled by Foley et al (2010a)
Grit & screenings	grit generation	[g/EP/d]	4.82									Calibrated to data from Gold Coast Water
	transport distance	[km]	20	Triangle			10	20	50			Default value from GCW.
	landfill gases	[kg-CO2e/kg]	1.11									Calibrated to data from Gold Coast Water
STP biological sludge	Solids generation	[kg-ds/kg-CODin]	0.357									Calibrated to data from Gold Coast Water
	P removal	[g-dP/kg-TCOD]	13.64									Calibrated to data from Gold Coast Water
	C concentration	[w/w-ds]	0.411									Following the modelling approach of de Haas et al (2009)
	N concentration	[kg-N/kg-ds]	0.075									Following the modelling approach of de Haas et al (2009)
STP chemical sludge	Solids generation	[kg-ds/kg-FeClx]	0.602									Calibrated to data from Gold Coast Water
Biosolids	transport distance	[km]	200	Triangle			60	200	300			Default value based on transport to Darling Downs. Min & max values chosen to explore wide possible range.
	moisture content	[w/w]	0.91 #									Gold Coast Water
Effluent	pumping power use	[kWh/ML]	291	Lognormal	291	1.10						Default calibrated to data from GCW.
	chlorine gas use	[kg/ML]	8.06	Lognormal	8.1	1.70						Default calibrated to data from GCW.
	reuse %	[v/v]	0.196	Triangle			0.15	0.196	0.25			Default value set equal to average (provided by Gold Coast Water) for all GC STPs. Assumed this might vary ±25% over the long term.
	NH4 concentration	[mg-N/l]	0.42	Lognormal	0.4	1.30						Default value from GCW. Variance informed by analysis of STPs undertaken by de Haas et al (2009)
	NOx concentration	[mg/l]	1.20	Lognormal	1.2	1.30						" " " " "
	DON concentration	[mg/l]	0.81	Lognormal	0.8	1.30						" " " " "
	PN concentration	[mg/l]	0.53	Lognormal	0.5	1.30						" " " " "
	DP concentration	[mg/l]	4.03	Lognormal	4.0	1.30						" " " " "
	PP concentration	[mg/l]	0.27	Lognormal	0.3	1.30						" " " " "
	COD concentration	[mg/l]	35.00	Lognormal	35.0	1.20						" " " " "
	C:COD ratio	[mg C/mg COD]	0.37									Following the modelling approach of de Haas et al (2009)
	TSS concentration	[mg/l]	7.00	Lognormal	7.0	1.30						Default value from GCW. Variance informed by analysis of STPs undertaken by de Haas et al (2009)
	free chlorine	[mg/L]	0.080	Lognormal	0.080	2.05						" " " " "
	monochloramine	[mg/L]	0.400	Lognormal	0.400	2.55						" " " " "

 # The Coombabah STP biosolids dry solids content was incorrectly set at 9%, without allowing for the moisture removal (to approx 25% dry solids) achieved by drying beds

Elanora STP

Group	Parameter	Units	Default value	Uncertainty distribution type	Uncertainty distribution parameters						Source
					lognormal		triangle		uniform		
					geometric mean	geometric SD	min	most likely	max	min	max	
STP	connected EP	[p]	92,328									Gold Coast Water
Raw sewage	Flow	[ML/d]	15.13									Gold Coast Water
	COD	[kg/d]	12,496	Lognormal	12,496	1.30						Default value from GCW. Variance informed by analysis of STPs undertaken by de Haas et al (2009)
	C:COD ratio	[mg-C/mg-COD]	0.3									Following the modelling approach of de Haas et al (2009)
	non-biogenic carbon fraction	[w/w]	0.1	Triangle			0.01	0.1	0.25			Max value taken from Griffith et al (2009). Min & ML values chosen to explore wide possible range.
	TKN	[kg/d]	1,271	Lognormal	1,271	1.27						Default value from GCW. Variance informed by analysis of STPs undertaken by de Haas et al (2009)
	TP	[kg/d]	247	Lognormal	247	1.26						Default value from GCW. Variance informed by analysis of STPs undertaken by de Haas et al (2009)
	dissolved CH4 concentration	[mg/l]	5	Triangle			1	5	30			Default and range taken from Guisasola et al (2008, 2009)
STP chemicals use	Ferrous Chloride	[kg/kg-dP]	12.9									Calibrated to data from Gold Coast Water
	Lime use	[kg/kg-dP]	17.6									Calibrated to data from Gold Coast Water
	Poly (dry) use	[g/kg-COD]	1.12									Calibrated to data from Gold Coast Water
STP digester	sludge rate	[ML/d]	0.3									Following the modelling approach of de Haas et al (2009)
	CH4 supersaturation concentration	[mg/L]	11.8									Following the modelling approach of de Haas et al (2009)
	CO2 supersaturation concentration	[mg/L]	133									Following the modelling approach of de Haas et al (2009)
	biogas generation	[kL/kg-dry]	0.62									Calibrated to data from Gold Coast Water
	biogas CH4 fraction	[v/v]	0.67									Following the modelling approach of de Haas et al (2009)
	biogas leak fraction	[w/w]	0.01									Following the modelling approach of de Haas et al (2009)
STP power	power use	[kWh/d]	14268	Lognormal	14268	1.22						Default calibrated to data from GCW. Variance informed by analysis of STPs undertaken by de Haas et al (2009)
STP power generation	power generation	[kWh/ML]	641.7									Calibrated to data from Gold Coast Water
	unoxidised CH4 fraction	[w/w]	0.00335									Following the modelling approach of de Haas et al (2009)
	NOx generation	[kg-NOx/ML]	3.6									Based on similar treatment systems modelled by Foley et al (2010a)
	SOx generation	[kg-NOx/ML]	4.8									Based on similar treatment systems modelled by Foley et al (2010a)
	CO generation	[kg-NOx/ML]	1.2									Based on similar treatment systems modelled by Foley et al (2010a)
STP fugitives	NH3 generation (overall)	[kg-NH3/kg-TN]	0.00002									Based on similar treatment systems modelled by Foley et al (2010a)
	N2O generation (overall)	[kg-N2O/kg-dN]	0.028	Lognormal	0.028	2.84						Geometric mean & geometric SD values calculated from the full dataset collected by Foley et al (2010b).
	CH4 generation (2° treatment)	[kg-CH4/d]	0									Based on similar treatment systems modelled by Foley et al (2010a)
Grit & screenings	grit generation	[g/EP/d]	1.64									Calibrated to data from Gold Coast Water
	transport distance	[km]	50	Triangle			20	50	65			Default value from GCW.
	landfill gases	[kg-CO2e/kg]	1.11									Following the modelling approach of de Haas et al (2009)
STP biological sludge	Solids generation	[kg-ds/kg-CODin]	0.322									Calibrated to data from Gold Coast Water
	P removal	[g-dP/kg-TCOD]	7.94									Calibrated to data from Gold Coast Water
	C concentration	[w/w-ds]	0.356									Following the modelling approach of de Haas et al (2009)
	N concentration	[kg-N/kg-ds]	0.065									Following the modelling approach of de Haas et al (2009)
STP chemical sludge	Solids generation	[kg-ds/kg-FeClx]	0.602									Calibrated to data from Gold Coast Water
Biosolids	transport distance	[km]	200	Triangle			60	200	300			Default value based on transport to Darling Downs. Min & max values chosen to explore wide possible range.
	moisture content	[w/w]	0.815									Gold Coast Water
Effluent	pumping power use	[kWh/ML]	350	Lognormal	350	1.10						Default calibrated to data from GCW.
	chlorine gas use	[kg/ML]	8.33	Lognormal	8.3	1.70						Default calibrated to data from GCW.
	reuse %	[v/v]	0.196	Triangle			0.15	0.196	0.25			Default value set equal to average (provided by Gold Coast Water) for all GC STPs. Assumed this might vary ±25% over the long term.
	NH4 concentration	[mg-N/l]	0.83	Lognormal	0.8	1.30						Default value from GCW. Variance informed by analysis of STPs undertaken by de Haas et al (2009)
	NOx concentration	[mg/l]	8.00	Lognormal	8.0	1.30						" " " " " "
	DON concentration	[mg/l]	0.54	Lognormal	0.5	1.30						" " " " " "
	PN concentration	[mg/l]	0.38	Lognormal	0.4	1.30						" " " " " "
	DP concentration	[mg/l]	2.71	Lognormal	2.7	1.30						" " " " " "
	PP concentration	[mg/l]	0.29	Lognormal	0.3	1.30						" " " " " "
	COD concentration	[mg/l]	35.00	Lognormal	35.0	1.20						" " " " " "
	C:COD ratio	[mg C/mg COD]	0.37									Following the modelling approach of de Haas et al (2009)
	TSS concentration	[mg/l]	7.00	Lognormal	7.0	1.30						Default value from GCW. Variance informed by analysis of STPs undertaken by de Haas et al (2009)
	free chlorine	[mg/L]	0.056	Lognormal	0.056	1.31						" " " " " "
	monochloramine	[mg/L]	0.018	Lognormal	0.018	1.64						" " " " " "

Merrimac STP

Group	Parameter	Units	Default value	Uncertainty distribution type	Uncertainty distribution parameters						Source
					lognormal		triangle		uniform		
					geometric mean	geometric SD	min	most likely	max	min	max	
STP	connected EP	[p]	135,353									Gold Coast Water
Raw sewage	Flow	[ML/d]	29.4									Gold Coast Water
	COD	[kg/d]	23,407	Lognormal	23,407	1.30						Default value from GCW. Variance informed by analysis of STPs undertaken by de Haas et al (2009)
	C:COD ratio	[mg-C/mg-COD]	0.3									Following the modelling approach of de Haas et al (2009)
	non-biogenic carbon fraction	[w/w]	0.1	Triangle			0.01	0.1	0.25			Max value taken from Griffith et al (2009). Min & ML values chosen to explore wide possible range.
	TKN	[kg/d]	1,700	Lognormal	1,700	1.27						Default value from GCW. Variance informed by analysis of STPs undertaken by de Haas et al (2009)
	TP	[kg/d]	358	Lognormal	358	1.26						Default value from GCW. Variance informed by analysis of STPs undertaken by de Haas et al (2009)
	dissolved CH4 concentration	[mg/l]	5	Triangle			1	5	30			Default and range taken from Guisasola et al (2008, 2009)
STP chems use	Poly (dry) use	[g/kg-COD]	1.45									Calibrated to data from Gold Coast Water
STP digester	sludge rate	[ML/d]	0									Following the modelling approach of de Haas et al (2009)
	CH4 supersaturation concentration	[mg/L]	11.8									Following the modelling approach of de Haas et al (2009)
	CO2 supersaturation concentration	[mg/L]	133									Following the modelling approach of de Haas et al (2009)
	biogas generation	[kL/kg-dry]	0.00									Calibrated to data from Gold Coast Water
	biogas CH4 fraction	[v/v]	0.67									Following the modelling approach of de Haas et al (2009)
	biogas leak fraction	[w/w]	0.01									Following the modelling approach of de Haas et al (2009)
STP power	power use	[kWh/d]	20559	Lognormal	20559	1.18						Default calibrated to data from GCW. Variance informed by analysis of STPs undertaken by de Haas et al (2009)
STP power generation	power generation	[kWh/ML]	0									Calibrated to data from Gold Coast Water
	unoxidised CH4 fraction	[w/w]	0.00335									Following the modelling approach of de Haas et al (2009)
	NOx generation	[kg-NOx/ML]	0									Based on similar treatment systems modelled by Foley et al (2010a)
	SOx generation	[kg-NOx/ML]	0									Based on similar treatment systems modelled by Foley et al (2010a)
	CO generation	[kg-NOx/ML]	0									Based on similar treatment systems modelled by Foley et al (2010a)
STP fugitives	NH3 generation (overall)	[kg-NH3/kg-TN]	0.0002									Based on similar treatment systems modelled by Foley et al (2010a)
	N2O generation (overall)	[kg-N2O/kg-dN]	0.021	Lognormal	0.021	1.95						Geometric mean & geometric SD values calculated from the full dataset collected by Foley et al (2010b).
	CH4 generation (2* treatment)	[kg-CH4/d]	0									Based on similar treatment systems modelled by Foley et al (2010a)
Grit & screenings	grit generation	[g/EP/d]	7.39	0								Calibrated to data from Gold Coast Water
	transport distance	[km]	50	0			20	50	65			Default value from GCW.
	landfill gases	[kg-CO2e/kg]	1.11									Calibrated to data from Gold Coast Water
STP biological sludge	Solids generation	[kg-ds/kg-CODin]	0.32									Calibrated to data from Gold Coast Water
	P removal	[g-dP/kg-TCOD]	13.16	Triangle								Calibrated to data from Gold Coast Water
	C concentration	[w/w-ds]	0.333									Following the modelling approach of de Haas et al (2009)
	N concentration	[kg-N/kg-ds]	0.075									Following the modelling approach of de Haas et al (2009)
STP chemical sludge	Solids generation	[kg-ds/kg-FeClx]	0.602									Calibrated to data from Gold Coast Water
Biosolids	transport distance	[km]	200	Triangle			60	200	300			Default value based on transport to Darling Downs. Min & max values chosen to explore wide possible range.
	moisture content	[w/w]	0.873									Gold Coast Water
Effluent	pumping power use	[kWh/ML]	129	Lognormal	129	1.10						Default calibrated to data from GCW.
	hypchlorite use	[kg/ML]	10.46	Lognormal	10.5	1.70						Default calibrated to data from GCW.
	reuse %	[v/v]	0.196	Triangle			0.15	0.196	0.25			Default value set equal to average (provided by Gold Coast Water) for all GC STPs. Assumed this might vary ±25% over the long term.
	NH4 concentration	[mg-N/l]	0.22	Lognormal	0.2	1.30						Default value from GCW. Variance informed by analysis of STPs undertaken by de Haas et al (2009)
	NOx concentration	[mg/l]	1.70	Lognormal	1.7	1.30						" " " "
	DON concentration	[mg/l]	0.56	Lognormal	0.6	1.30						" " " "
	PN concentration	[mg/l]	0.53	Lognormal	0.5	1.30						" " " "
	DP concentration	[mg/l]	1.41	Lognormal	1.4	1.30						" " " "
	PP concentration	[mg/l]	0.29	Lognormal	0.3	1.30						" " " "
	COD concentration	[mg/l]	35.00	Lognormal	35.0	1.20						" " " "
	C:COD ratio	[mg C/mg COD]	0.37									Following the modelling approach of de Haas et al (2009)
	TSS concentration	[mg/l]	7.00	Lognormal	7.0	1.30						Default value from GCW. Variance informed by analysis of STPs undertaken by de Haas et al (2009)
	free chlorine	[mg/L]	0.100	Lognormal	0.100	1.81						" " " "
	monochloramine	[mg/L]	0.260	Lognormal	0.260	1.87						" " " "

Group	Parameter	Units	Default value	Uncertainty distribution type	Uncertainty distribution parameters							Source
					lognormal		triangle			uniform		
					geometric mean	geometric SD	min	most likely	max	min	max	
STP	connected EP	[p]	125,275									Gold Coast Water
Raw sewage	Flow	[ML/d]	17.1									Gold Coast Water
	COD	[kg/d]	12,564	Lognormal	12,564	1.21						Default value from GCW. Variance informed by analysis of STPs undertaken by de Haas et al (2009)
	C:COD ratio	[mg-C/mg-COD]	0.3									Following the modelling approach of de Haas et al (2009)
	non-biogenic carbon fraction	[w/w]	0.1	Triangle			0.01	0.1	0.25			Max value taken from Griffith et al (2009). Min & ML values chosen to explore wide possible range.
	TKN	[kg/d]	1,124	Lognormal	1,124	1.32						Default value from GCW. Variance informed by analysis of STPs undertaken by de Haas et al (2009)
	TP	[kg/d]	235	Lognormal	235	1.32						Default value from GCW. Variance informed by analysis of STPs undertaken by de Haas et al (2009)
	dissolved CH4 concentration	[mg/l]	5	Triangle			1	5	30			Default and range taken from Guisasola et al (2008, 2009)
STP chemicals use	Ferrous Chloride	[kg/kg-dP]	41.7									Calibrated to data from Gold Coast Water
	Lime use	[kg/kg-dP]	6	Lognormal	6	1.81						Calibrated to data from Gold Coast Water
	Poly (dry) use	[g/kg-COD]	3.93									Calibrated to data from Gold Coast Water
STP power	power use	[kWh/d]	4579	Lognormal	4579	1.08						Default calibrated to data from GCW. Variance informed by analysis of STPs undertaken by de Haas et al (2009)
STP power generation	power generation	[kWh/ML]	0									Calibrated to data from Gold Coast Water
	unoxidised CH4 fraction	[w/w]	0.00335									Following the modelling approach of de Haas et al (2009)
	NOx generation	[kg-NOx/ML]	0									Based on similar treatment systems modelled by Foley et al (2010a)
	SOx generation	[kg-NOx/ML]	0									Based on similar treatment systems modelled by Foley et al (2010a)
	CO generation	[kg-NOx/ML]	0									Based on similar treatment systems modelled by Foley et al (2010a)
STP fugitives	NH3 generation (overall)	[kg-NH3/kg-TN]	0.0002									Based on similar treatment systems modelled by Foley et al (2010a)
	N2O generation (overall)	[kg-N2O/kg-dN]	0.021	Lognormal	0.021	1.95						Geometric mean & geometric SD values calculated from the full dataset collected by Foley et al (2010b).
	CH4 generation (2° treatment)	[kg-CH4/d]	0									Based on similar treatment systems modelled by Foley et al (2010a)
Grit & screenings	grit generation	[g/EP/d]	4.82									Calibrated to data from Gold Coast Water
	transport distance	[km]	15	Triangle			5	15	35			Default value from GCW.
	landfill gases	[kg-CO2e/kg]	1.11									Following the modelling approach of de Haas et al (2009)
STP biological sludge	Solids generation	[kg-ds/kg-COD]	0.465									Calibrated to data from Gold Coast Water
	P removal	[g-dP/kg-TCOD]	11.41									Calibrated to data from Gold Coast Water
	C concentration	[w/w-ds]	0.411									Following the modelling approach of de Haas et al (2009)
	N concentration	[kg-N/kg-ds]	0.075									Following the modelling approach of de Haas et al (2009)
STP chemical sludge	Solids generation	[kg-ds/kg-FeClx]	0.602									Calibrated to data from Gold Coast Water
Biosolids	transport distance	[km]	200	Triangle			60	200	300			Default value based on transport to Darling Downs. Min & max values chosen to explore wide possible range.
	moisture content	[w/w]	0.851									Gold Coast Water
Effluent	pumping power use	[kWh/ML]	291	Lognormal	291	1.10						Default calibrated to data from GCW.
	hypochlorite use	[kg/ML]	21.6	Triangle			8.4	21.6	42.2			Default calibrated to data from GCW.
	reuse %	[v/v]	0.196	Triangle			0.15	0.196	0.25			Default value set equal to average (provided by Gold Coast Water) for all GC STPs. Assumed this might vary ±25% over the long term.
	NH4 concentration	[mg-N/l]	0.05	Lognormal	0.1	2.51						Default value from GCW. Variance informed by analysis of STPs undertaken by de Haas et al (2009)
	NOx concentration	[mg/l]	0.47	Lognormal	0.5	1.47						" " " " " "
	DON concentration	[mg/l]	0.83	Lognormal	0.8	1.39						" " " " " "
	PN concentration	[mg/l]	0.21	Lognormal	0.2	1.41						" " " " " "
	DP concentration	[mg/l]	0.23	Lognormal	0.2	2.92						" " " " " "
	PP concentration	[mg/l]	0.11	Lognormal	0.1	1.29						" " " " " "
	COD concentration	[mg/l]	29.68	Lognormal	29.7	1.20						" " " " " "
	C:COD ratio	[mg C/mg COD]	0.37									Following the modelling approach of de Haas et al (2009)
	TSS concentration	[mg/l]	3.01	Lognormal	3.0	1.29						Default value from GCW. Variance informed by analysis of STPs undertaken by de Haas et al (2009)
	free chlorine	[mg/L]	0.400	Lognormal	0.400	2.55						" " " " " "
	monochloramine	[mg/L]	0.000									" " " " " "

Group	Parameter	Units	Default value	Uncertainty distribution parameters							Source
				lognormal		triangle			uniform		
				geometric mean	geometric SD	min	most likely	max	min	max	
Feed	Pumping power use	[kWh/ML-inf]	0								Incorporated into AWTP treatment energy
AWTP	Backwash rate	[fraction]	0.01								Calibrated to GCW data
	Treatment power use (flow specific)	[kWh/ML-inf]	255	255	1.10						Default value calibrated to GCW data, assuming 90% of measured power use is flow dependent. Variance informed by GCW power data for STPs and AWTPs.
	Treatment power use (fixed)	[MWh/d]	0.37	0.37	1.20						" " " "
	reject stream denitrification N2O emissions	[kg-N2O/kg-dN]	0.0206	0.0206	1.95						Used STP data from Foley et al (2010b) - excl. the MLE datasets - as a conservative (on upside) estimate
AWTP chemicals	Alum Sulphate use	[kg/ML]	19.6	19.6	1.36						Default value calibrated to GCW data. Variance taken from GCW data.
	Citric Acid use	[kg/ML]	0.2	0.2	18.74						" " " "
	Sodium Hypochlorite use	[kg/ML]	260.2	260.2	1.42						" " " "
	Sulphuric Acid use	[kg/ML]	0.4	0.4	8.55						" " " "
Product water	DON concentration	[mg/l]	0.51	0.51	1.30						Default & variance from GCW data
	DP concentration	[mg/l]	0.16	0.16	2.14						" " "
	NH4 concentration	[mg/l]	0.02	0.02	1.93						" " "
	NOx concentration	[mg/l]	0.48	0.48	1.50						" " "
	TOC concentration	[mg/l]	0.00								" " "
	C:COD ratio	[mg C/mg COD]	0.37								Assumed same as for secondary effluent
Product water to sea	Hypochlorite use	[kg/ML]	92.6	92.6	1.20						Default value calibrated to GCW data. Variance taken from GCW data.
	Pumping power use	[kWh/ML]	436	436	1.10						" " " "
	Free chlorine concentration	[mg/L]	1.1	1.1	1.96						Default & variance from GCW data
	Chloramine concentration	[mg/L]	0.8	0.8	1.96						" " "
Recycled water	Household internal use	[ML/d]	1.8								Calculated from household water balance
	Household external use	[ML/d]	2.1								Calculated from household water balance
	Non residential use	[ML/d]	3.4								Non residential usage fraction set equal to Class B reuse fraction for STPs
	Hypochlorite use	[kg/ML]	92.6	92.6	1.20						Default value calibrated to GCW data. Variance taken from GCW data.
	Pumping power use	[kWh/ML]	436	436	1.10						" " " "
	Free chlorine concentration	[mg/L]	1.1	1.1	1.74						Default & variance from GCW data
	Chloramine concentration	[mg/L]	0.8	0.8	1.74						" " "
Sludge	Solids generation	[kg-ds/kg-alum]	0.14								Calibrated to GCW data
	Transport distance	[km]	200			60	200	300			Sludge mixed with biosolids for disposal

Group	Parameter	Units	Default value	Uncertainty distribution parameters									Source
				lognormal		normal		triangle			uniform		
				geometric mean	geometric SD	mean	SD	min	most likely	max	min	max	
Pimpama AWTP product water recovery	Aluminium	[w/w]	0.43										Based on data Pimpama data provided by GCW
	Antimony	[w/w]	1.00										" " " "
	Arsenic	[w/w]	1.00										" " " "
	Barium	[w/w]	1.00										" " " "
	Boron	[w/w]	0.90										" " " "
	Cadmium	[w/w]	1.00										" " " "
	Calcium	[w/w]	1.00										" " " "
	Chromium	[w/w]	0.77										" " " "
	Cobalt	[w/w]	1.00										" " " "
	Copper	[w/w]	0.45										" " " "
	Iron	[w/w]	0.08										" " " "
	Lead	[w/w]	1.00										" " " "
	Lithium	[w/w]	1.00										" " " "
	Magnesium	[w/w]	0.30										" " " "
	Manganese	[w/w]	0.02										" " " "
	Mercury	[w/w]	1.00										" " " "
	Molybdenum	[w/w]	1.00										" " " "
	Nickel	[w/w]	0.97										" " " "
	Potassium	[w/w]	0.78										" " " "
	Sodium	[w/w]	0.58										" " " "
	Strontium	[w/w]	1.00										" " " "
	Vanadium	[w/w]	0.07										" " " "
	Zinc	[w/w]	1.00										" " " "
Pimpama AWTP product water recovery	2,4,6-Trichlorophenol	[w/w]	1.00										Assumed that AWTP achieved no organics removal
	Pentachlorophenol	[w/w]	1.00										" " " "
	Acenaphthye	[w/w]	1.00										" " " "
	Metolachlor	[w/w]	1.00										" " " "
	Tri-allate	[w/w]	1.00										" " " "
	Ametryn	[w/w]	1.00										" " " "
	Atrazine	[w/w]	1.00										" " " "
	Desisopropyl Atrazine	[w/w]	1.00										" " " "
	Diuron	[w/w]	1.00										" " " "
	Simazine	[w/w]	1.00										" " " "
	Tebuconaz	[w/w]	1.00										" " " "
	DEET	[w/w]	1.00										" " " "
	Triclopyr	[w/w]	1.00										" " " "
	Acetone	[w/w]	1.00										" " " "
	NDMA	[w/w]	1.00										" " " "
	EDTA	[w/w]	1.00										" " " "
	4-t-Octylphenol	[w/w]	1.00										" " " "
	Nonylphenol	[w/w]	1.00										" " " "
	Bisphenol A	[w/w]	1.00										" " " "

Group	Parameter	Units	Default value	Uncertainty distribution type	Uncertainty distribution parameters							Source
					lognormal		triangle			uniform		
					geometric mean	geometric SD	min	most likely	max	min	max	
Feed	Pumping power use	[kWh/ML-inf]	176	Lognormal	176	1.06						Default value calibrated to Water Secure data. Variance based on analysis of STP & Pimpama AWTP data.
AWTP	Backwash rate	[fraction]	0.02									Calibrated to Water Secure data
	Reject rate	[fraction]	0.16									Calibrated to Water Secure data
	Treatment power use	[kWh/ML-inf]	782	Lognormal	782	1.10						Default value calibrated to Water Secure data. Variance based on analysis of STP & Pimpama AWTP data.
	reject stream denitrification N2O emissions	[kg-N2O/kg-dN]	0.0206	Lognormal	0.0206	1.95						Used STP data from Foley et al (2010b) - excl. the MLE datasets - as a conservative (on upside) estimate
AWTP chemicals	Methanol use	[kg/kg-dN]	8.3									Calibrated to Water Secure data
	Ferrous Chloride use	[kg/kg-dP]	43.7									Calibrated to Water Secure data
	Ammonium Sulphate use	[kg/ML]	16.8	Lognormal	16.78	1.20						Default value calibrated to Water Secure data. Variance based on analysis of STP & Pimpama AWTP data.
	Anti scalant (carboxylate) use	[kg/ML]	0.7	Lognormal	0.7	1.20						" " " "
	Anti scalant (phosphonate) use	[kg/ML]	1.0	Lognormal	1	1.20						" " " "
	Carbon Dioxide use	[kg/ML]	16.2	Lognormal	16.23	1.20						" " " "
	Citric Acid use	[kg/ML]	1.1	Lognormal	1.09	1.20						" " " "
	Hydrogen Peroxide use	[kg/ML]	7.7	Lognormal	7.66	1.20						" " " "
	Hydrated Lime use	[kg/ML]	28.6	Lognormal	28.61	1.20						" " " "
	Poly (liquid) use	[kg/ML]	0.4	Lognormal	0.37	1.20						" " " "
	Poly (dry) use	[kg/ML]	0.2	Lognormal	0.24	1.20						" " " "
	Sodium Bisulphite use	[kg/ML]	0.4	Lognormal	0.38	1.20						" " " "
	Sodium Hydroxide use	[kg/ML]	1.8	Lognormal	1.78	1.20						" " " "
	Sodium Hypochlorite use	[kg/ML]	117.8	Lognormal	117.82	1.20						" " " "
	Sulphuric Acid use	[kg/ML]	17.9	Lognormal	17.91	1.20						" " " "
Product water	DP concentration	[mg/l]	0.02	Lognormal	0.02	1.20						Default value as per Water Secure data. Variance based on analysis of STP & Pimpama AWTP data.
	TOC concentration	[mg/l]	0.05	Lognormal	0.05	1.20						" " " "
	C:COD ratio	[mg C/mg COD]	0.37									Assumed same as for secondary effluent
	NH4 recovery	[kg-N prod/kg-N inf]	0.08									Calibrated to Water Secure data
	TN recovery	[kg-N prod/kg-N inf]	0.10									Calibrated to Water Secure data
	Chlorine concentration	[mg/L]	0.00									As per Water Secure data
	Pumping power use	[kWh/ML]	639	Triangle			447.3	639	702.9			Default value calibrated to Water Secure data. Variance based on analysis of STP & Pimpama AWTP data.
Reject stream	DP concentration	[mg/l]	0.89	Lognormal	0.89	1.20						Default value as per Water Secure data. Variance based on analysis of STP & Pimpama AWTP data.
	NH4 concentration	[mg/l]	0.14	Lognormal	0.14	1.20						" " " "
	NOx concentration	[mg/l]	13.33	Lognormal	13.33	1.20						" " " "
	Chlorine concentration	[mg/L]	0.04	Lognormal	0.043	1.74						" " " "
	Pumping power use	[kWh/ML]	291	Lognormal	291.3	1.10						Default value calibrated to Water Secure data. Variance based on analysis of STP & Pimpama AWTP data.
Sludge	moisture content	[w/w]	0.80									As per Water Secure data
	Transport distance	[km]	20.00	Triangle			10	20	50			Default & range set as per Coombabah STP
	Solids generation	[kg-ds/kg-FeClx]	0.52									Calibrated to Water Secure data

Group	Parameter	Units	Default value	Uncertainty distribution parameters									Source
				lognormal		normal		triangle			uniform		
				geometric mean	geometric SD	mean	SD	min	most likely	max	min	max	
Coombabah AWTP product water recovery	Aluminium	[w/w]	1.00										Based on data provided by Water Secure (2010)
	Antimony	[w/w]	0.20										" " " "
	Arsenic	[w/w]	0.04										" " " "
	Barium	[w/w]	1.00										" " " "
	Boron	[w/w]	0.79										" " " "
	Cadmium	[w/w]	0.19										" " " "
	Calcium	[w/w]	0.71										" " " "
	Chromium	[w/w]	0.51										" " " "
	Cobalt	[w/w]	0.32										" " " "
	Copper	[w/w]	0.67										" " " "
	Iron	[w/w]	0.65										" " " "
	Lead	[w/w]	0.67										" " " "
	Lithium	[w/w]	1.00										" " " "
	Magnesium	[w/w]	0.04										" " " "
	Manganese	[w/w]	0.10										" " " "
	Mercury	[w/w]	0.84										" " " "
	Molybdenum	[w/w]	0.21										" " " "
	Nickel	[w/w]	0.28										" " " "
	Potassium	[w/w]	0.17										" " " "
	Sodium	[w/w]	0.00										" " " "
	Strontium	[w/w]	1.00										" " " "
	Vanadium	[w/w]	0.28										" " " "
	Zinc	[w/w]	0.08										" " " "
Coombabah AWTP RO product water recovery	2,4,6-Trichlorophenol	[w/w]	0.50										Based on data provided by Water Secure (2010)
	Pentachlorophenol	[w/w]	0.50										" " " "
	Acenaphthye	[w/w]	0.50										" " " "
	Metolachlor	[w/w]	0.50										" " " "
	Tri-allate	[w/w]	0.50										" " " "
	Ametryn	[w/w]	0.50										" " " "
	Atrazine	[w/w]	0.50										" " " "
	Desisopropyl Atrazine	[w/w]	0.65										" " " "
	Diuron	[w/w]	0.50										" " " "
	Simazine	[w/w]	0.50										" " " "
	Tebuconaz	[w/w]	0.50										" " " "
	DEET	[w/w]	0.50										" " " "
	Triclopyr	[w/w]	0.50										" " " "
	Acetone	[w/w]	0.50										" " " "
	NDMA	[w/w]	0.90										" " " "
	EDTA	[w/w]	0.50										" " " "
	4-t-Octylphenol	[w/w]	0.96										" " " "
	Nonylphenol	[w/w]	0.84										" " " "
	Bisphenol A	[w/w]	0.50										" " " "
Coombabah AWTP removal in final oxidation step	2,4,6-Trichlorophenol	[w/w]	1.00										Based on data provided by Water Secure (2010)
	Pentachlorophenol	[w/w]	1.00										" " " "
	Acenaphthye	[w/w]	1.00										" " " "
	Metolachlor	[w/w]	1.00										" " " "
	Tri-allate	[w/w]	1.00										" " " "
	Ametryn	[w/w]	0.98										" " " "
	Atrazine	[w/w]	0.98										" " " "
	Desisopropyl Atrazine	[w/w]	0.50										" " " "
	Diuron	[w/w]	0.99										" " " "
	Simazine	[w/w]	0.97										" " " "
	Tebuconaz	[w/w]	1.00										" " " "
	DEET	[w/w]	1.00										" " " "
	Triclopyr	[w/w]	0.93										" " " "
	Acetone	[w/w]	0.89										" " " "
	NDMA	[w/w]	0.51										" " " "
	EDTA	[w/w]	0.96										" " " "
	4-t-Octylphenol	[w/w]	0.50										" " " "
	Nonylphenol	[w/w]	0.50										" " " "
	Bisphenol A	[w/w]	0.55										" " " "

Group	Parameter	Units	Default value	Uncertainty distribution parameters							Source
				lognormal		triangle			uniform		
				geometric mean	geometric SD	min	most likely	max	min	max	
Feed water	Pumping power use	[kWh/ML-inf]	133	133	1.06						Munoz et al (2008), Vince et al (2009), Mrayed & Leslie (2009) and Leslie (2010)
	Hypochlorite use (shock dosing)	[kg/ML-inflow]	10.4	10.41	1.10						" " " "
Treatment plant	Power use	[kWh/ML-inf]	1453	1453	1.04						" " " "
	Ferric Sulphate use	[kg/ML-inflow]	10.1			5.75	10.1	14.375			" " " "
	Poly (liquid) use	[kg/ML-inflow]	0.2			0.1	0.23	0.4			" " " "
	Sodium Bisulphite use	[kg/ML-inflow]	3.6	3.64	1.10						" " " "
	Sulphuric Acid use	[kg/ML-inflow]	17.9	17.91	1.10						" " " "
	Antiscalant use	[kg/ML-inflow]	1.3	1.25	1.05						" " " "
	Lime use	[kg/ML-prod]	30.0	30	1.10						" " " "
	CO2 use	[kg/ML-prod]	35.0	35	1.10						" " " "
Membrane use	materials	[kg/ML-pw]	0.24								
	transport distance (Australia)	[km]	1,000								
	transport distance (shipping)	[km]	12,068								
Product water	Flow	[ML/d]	125								QWC (2010)
	Product fraction reaching Tarrant Dve pump station	[fraction]	0.2			0.1	0.2	0.4			Estimated fraction of delivery mains length after the Tarrant Dve pump station, based on maps published in GCD (2006)
	Tugun pump station power use	[kWh/ML]	360			310	360	414			Hall et al (2009)
	Tarrant Dve pump station power use	[kWh/ML]	200			170	200	230			Hall et al (2009)
	Hypochlorite use	[kg/ML]	2.1								Munoz et al (2008), Vince et al (2009), Mrayed & Leslie (2009) and Leslie (2010)
Sludge	generation rate	[kg-ws/ML-inf]	46.0								Based on ferric sludge generation rate predicted in Water Corporation (2008).
	trucking distance	[km]	50								Following Water Corporation (2008), assumed that ferric sludge is trucked to landfill. Trucking distance matched to that from Elanora STP to landfill

Fertiliser Supply and Use

Group	Parameter	Units	Default value	Uncertainty distribution type	Uncertainty distribution parameters								Source
					lognormal		normal		triangle		uniform		
					geometric mean	geometric SD	mean	SD	min	most likely	max	min	max	
DAP nutrients	N concentration	[w/w fraction]	0.18											
	P concentration	[w/w]	0.20											
	N uptake	[w/w]	1.0											Assume that 100% of N (not lost to waterways or atmosphere) is available for crop uptake.
	P uptake	[w/w]	1.0											Assume that 100% of P (not lost to waterways or atmosphere) is available for crop uptake.
DAP metals concentrations	Arsenic	[mg-As / kg-ds]	16.0	Triangle					10	16	22.6			Default value & range taken from Foley et al (2010a)
	Cadmium	[mg-Cd / kg-ds]	20.0	Triangle					3.8	20	93.4			" " "
	Chromium	[mg-Cr / kg-ds]	133.5	Triangle					63.5	133.5	402			" " "
	Copper	[mg-Cu / kg-ds]	2.9	Triangle					1.4	2.9	34.5			" " "
	Lead	[mg-Pb / kg-ds]	8.0	Triangle					4.9	8	16.3			" " "
	Mercury	[mg-Hg / kg-ds]	0.1	Triangle					0	0.1	1.1			" " "
	Molybdenum	[mg-Mo / kg-ds]	13.0	Triangle					2.6	13	21			" " "
	Nickel	[mg-Ni / kg-ds]	24.5	Triangle					3.5	24.5	153.1			" " "
	Selenium	[mg-Se / kg-ds]	1.0	Triangle					0.8	1	10			" " "
	Zinc	[mg-Zn / kg-ds]	135.0	Triangle					20.5	135	1319			" " "
Urea nutrients	N concentration	[w/w]	0.46											
	N uptake	[w/w]	1.0											Assume that 100% of N (not lost to waterways or atmosphere) is available for crop uptake.
Urea metals concentrations	Cadmium	[mg-Cd / kg-ds]	0.8	Uniform								0.5	1	Max concentration from Incitec Pivot (2010) - assumed min = 50% of max; default = 75% of max
	Flourine	[mg-Fl / kg-ds]	75.0	Uniform								50	100	" " "
	Lead	[mg-Pb / kg-ds]	0.8	Uniform								0.5	1	" " "
	Mercury	[mg-Hg / kg-ds]	0.2	Uniform								0.1	0.2	" " "
Fertilisers (general)	N losses to waterways	[w/w]	0.067	Uniform								0	0.067	Default value taken from the "fertiliser to soil" fate factor (seawater) from table 5 of Goedkoop et al (2009 - supp info). Following rationale for biosolids, assume this is at worst end of possible range.
	P losses to waterways	[w/w]	0.053	Uniform								0	0.053	Default value taken from the "fertiliser to soil" fate factor (seawater) from table 6.4 of Goedkoop et al (2009 - supp info). Following rationale for biosolids, assume this is at worst end of possible range.
	N2O emissions	[kg-N2O/kg-N applied]	0.016	Triangle					0.005	0.016	0.047			Min, ML & Max values taken from the "Low range", Mid range" & "High range" values (respectively) used by Foley et al (2010a)
	NH3 emissions	[kg-NH3/kg-N load]	0.121	Triangle					0.036	0.121	0.364			Min, ML & Max values taken from the "Low range", Mid range" & "High range" values (respectively) used by Foley et al (2010a)
	transport distance	[km]	50											

Group	Parameter	Units	Default value	Uncertainty distribution parameters							Source
				lognormal		triangle			uniform		
				geometric mean	geometric SD	min	most likely	max	min	max	
Application	Tractor fuel use	[L/t-wet]	0.325								Foley et al (2010a)
Offsets	Irrigation offset (by H2O content)	[v/v]	0								
Offsets	N uptake	[w/w]	0.50			0.25	0.50	0.75			Default & range taken from bioavailabilities used by Foley et al (2010a)
	P uptake	[w/w]	0.100			0.034	0.100	0.286			Barry (2006) gives a typical synthetic P fertilisation rate of 20-40kg/ha for the Qld crops in their trial, & biosolids P application rates >400kg/ha. Default value calculated as ratio of 40/400=0.1% Pritchard (2007) gives biosolids P application rates ranging from 140-560 kg/ha. Min value calculated as ratio of 20/560=0.034; Max value calculated as ratio of 40/140=0.286
Losses	N losses to waterways	[w/w]	0.0598						0	0.0598	Default value taken from the "manure to soil" fate factor (seawater) from table 5 of Goodkoep et al (2009 - supplementary info). Assumed that European loss factors at worst case end of spectrum. Given potential for complete groundwater denitrification before reaching waterways, set min loss ratio = zero.
	P losses to waterways	[w/w]	0.05						0	0.05	Default value taken from the "manure to soil" fate factor (seawater) from table 6.4 of Goodkoep et al (2009 - supplementary info). P leaching unlikely in Darling Downs - possible in coastal sandy soils. Assume that European loss factors are predominantly via leaching and therefore at worst case end of spectrum. Given potential for zero losses in the event that surface runoff is well managed, set min loss ratio = zero.
	N2O emissions	[kg-N20/kg-N applied]	0.0157			0.0047	0.0157	0.0471			Min, ML & Max values taken from the "Low range", Mid range" & "High range" values (respectively) used by Foley et al (2010a)
	NH3 emissions	[kg-NH3/kg-N load]	0.243			0.061	0.243	0.608			Min, ML & Max values taken from the "Low range", Mid range" & "High range" values (respectively) used by Foley et al (2010a)
	CH4 emissions	[kg-CH4/kg-ds]	0.0028			0.0000	0.0028	0.0096			Min, ML (median) & Max values calculated from the literature values collected by Foley et al (2007).
	C sequestration	[kg/kg applied]	0.1			0	0.1	0.2			Min, ML & Max values taken from the "Low range", Mid range" & "High range" values (respectively) used by Foley et al (2010a)
Micropollutant concentrations	Aluminium (baseline)	[mg/kg-ds]	0								
	Iron (baseline)	[mg/kg-ds]	0								
	As	[mg/kg-ds]	6.39	6.39	1.24						Default & geomean set to weighted average (dry solids basis) of means from BL,CB,EL,MM plants. GeoSD^2 set to average (BL,CB,EL,MM) of (mean+2*SD)/mean
	Cd	[mg/kg-ds]	1.07	1.07	1.28						" " " " " "
	Cr	[mg/kg-ds]	32.86	32.86	1.25						" " " " " "
	Cu	[mg/kg-ds]	467.20	467.20	1.30						" " " " " "
	Hg	[mg/kg-ds]	0.76	0.76	1.38						" " " " " "
	Ni	[mg/kg-ds]	29.15	29.15	1.29						" " " " " "
	Pb	[mg/kg-ds]	18.73	18.73	1.27						" " " " " "
	Se	[mg/kg-ds]	4.05	4.05	1.31						" " " " " "
	Zn	[mg/kg-ds]	632.26	632.26	1.26						" " " " " "
	Mo	[mg/kg-ds]	6.80			3.40	6.80	7.40			min=10%ile; ML=50%ile; max=90%ile values from Foley et al (2010a)
	Aldrin	[mg/kg-ds]	0.010	0.010	1.06						Default & geomean set to weighted average (dry solids basis) of means from BL,CB,EL,MM plants. GeoSD^2 set to average (BL,CB,EL,MM) of (mean+2*SD)/mean
	Chlordane	[mg/kg-ds]	0.013	0.013	1.30						" " " " " "
	DDD	[mg/kg-ds]	0.010	0.010	1.06						" " " " " "
	DDE	[mg/kg-ds]	0.010	0.010	1.14						" " " " " "
	DDT	[mg/kg-ds]	0.012	0.012	1.06						" " " " " "
	Dieldrin	[mg/kg-ds]	0.061	0.061	1.45						" " " " " "
	Heptachlor	[mg/kg-ds]	0.011	0.011	1.30						" " " " " "
	Lindane	[mg/kg-ds]	0.010	0.010	1.06						" " " " " "

STP Wastewater Disposal (generic)

Group	Parameter	Units	Default value	Uncertainty distribution parameters							Source
				lognormal		triangle			uniform		
				geometric mean	geometric SD	min	most likely	max	min	max	
Effluent disposal (freshwater)	N2O emissions	[kg-N2O/kg-N load]	2.4E-03			6.3E-05	2.4E-03	1.2E-02			Min, ML (median) & Max values calculated from the literature values collected by Foley et al (2007).
Effluent disposal (marine)	N2O emissions	[kg-N2O/kg-N load]	7.9E-04			9.0E-06	7.9E-04	9.4E-03			Min, ML (median) & Max values calculated from the literature values collected by Foley et al (2007).
Effluent irrigation (general)	N uptake	[w/w]	0.96						0.5	0.96	Default value assumes that all N is available for crop uptake, other than losses to waterways & atmosphere.
	P uptake	[w/w]	1.0						0.7	1.0	Default value assumes that all P is available for crop uptake, other than losses to waterways.
	N2O emissions	[kg-N2O/kg-N load]	0.0126			0.0031	0.0126	0.0346			Min, ML (median) & Max values calculated from the literature values collected by Foley et al (2007).
	NH3 emissions	[kg-NH3/kg-N load]	0.036								Assumed equal to the minimum NH_3 rate for synthetic fertilisers
Effluent irrigation (non residential)	Irrigation offset	[v/v]	0.33			0.25	0.33	0.75			Assumed that 67% of Class B irrigation is additional to any default use directly from local streams. Wide range included given lack of data.
	N offset availability	[w/w]	0.5			0.0	0.5	0.5			Allowance made for some avoidance of fertilisation on golf courses and agricultural lands
	P offset availability	[w/w]	0.5			0.0	0.5	0.5			Allowance made for some avoidance of fertilisation on golf courses and agricultural lands
	N losses to waterways	[w/w]	0.00			0.00	0.00	0.01			Assume losses very unlikely because of low concentration & well managed application.
	P losses to waterways	[w/w]	0.00			0.00	0.00	0.01			Assume losses very unlikely because of low concentration & well managed application.
Effluent irrigation (household)	N losses to waterways	[w/w]	0.01			0.00	0.01	0.01			Assume losses unlikely because of low concentrations, but more likely than for non-residential reuse.
	P losses to waterways	[w/w]	0.01			0.00	0.01	0.01			Assume losses unlikely because of low concentrations, but more likely than for non-residential reuse.

Group	Parameter	Units	Default value	Uncertainty distribution parameters									Source
				lognormal		normal		triangle			uniform		
				geometric mean	geometric SD	mean	SD	min	most likely	max	min	max	
Secondary effluent metals concentration	Aluminium	[mg/L]	0.0231	0.0231	1.6								Flow-weighted average of GCW data for Beenleigh, Coombabah, Elanora & Merrimac STPs
	Antimony	[mg/L]	0.0004	0.0004	1.5								" " " "
	Arsenic	[mg/L]	0.0011	0.0011	1.5								" " " "
	Barium	[mg/L]	0.0110	0.0110	1.5								" " " "
	Boron	[mg/L]	0.1530	0.1530	1.6								" " " "
	Cadmium	[mg/L]	0.0002	0.0002	1.5								" " " "
	Calcium	[mg/L]	31.2052	31.2052	1.2								" " " "
	Chromium	[mg/L]	0.0006	0.0006	1.9								" " " "
	Cobalt	[mg/L]	0.0001	0.0001	1.5								" " " "
	Copper	[mg/L]	0.0051	0.0051	1.8								" " " "
	Iron	[mg/L]	0.0547	0.0547	1.4								" " " "
	Lead	[mg/L]	0.0011	0.0011	1.9								" " " "
	Lithium	[mg/L]	0.0050	0.0050	1.0								" " " "
	Magnesium	[mg/L]	16.4810	16.4810	1.4								" " " "
	Manganese	[mg/L]	0.0660	0.0660	1.6								" " " "
	Mercury	[mg/L]	0.00005	0.00005	1.9								" " " "
	Molybdenum	[mg/L]	0.0019	0.0019	1.8								" " " "
	Nickel	[mg/L]	0.0024	0.0024	1.2								" " " "
	Potassium	[mg/L]	17.1869	17.1869	1.3								" " " "
	Sodium	[mg/L]	196.3698	196.3698	1.2								" " " "
	Strontium	[mg/L]	0.2003	0.2003	1.2								" " " "
	Vanadium	[mg/L]	0.0069	0.0069	1.5								" " " "
	Zinc	[mg/L]	0.0174	0.0174	1.7								" " " "
Secondary effluent organics concentration	2,4,6-Trichlorophenol	[µg/L]	609										Watkinson et al. (2009), Farre Olalla (2009), Reungoat et al. (2010)
	Pentachlorophenol	[µg/L]	409										" " " "
	Acenaphthye	[µg/L]	0.018										" " " "
	Metolachlor	[µg/L]	1.700										" " " "
	Tri-allate	[µg/L]	0.070										" " " "
	Ametryn	[µg/L]	0.050										" " " "
	Atrazine	[µg/L]	0.510										" " " "
	Desisopropyl Atrazine	[µg/L]	0.020										" " " "
	Diuron	[µg/L]	0.810										" " " "
	Simazine	[µg/L]	0.650										" " " "
	Tebuconaz	[µg/L]	5.100										" " " "
	DEET	[µg/L]	0.200										" " " "
	Triclopyr	[µg/L]	0.400										" " " "
	Acetone	[µg/L]	4.200										" " " "
	NDMA	[µg/L]	0.007										" " " "
	EDTA	[µg/L]	365										" " " "
	4-t-Octylphenol	[µg/L]	0.366										" " " "
	Nonylphenol	[µg/L]	0.467										" " " "
	Bisphenol A	[µg/L]	0.176										" " " "

Group	Parameter	Units	Default value	Uncertainty distribution parameters							Source
				lognormal		triangle			uniform		
				geometric mean	geometric SD	min	most likely	max	min	max	
Tanks for external use	Rainwater yield	[kL/d]	0.084								Modelling with TANK software (Vieritz et al 2007)
	Pumping power use	[kWh/kl]	0.80	0.80	2.46						Defalt value from Retamal et al (2009). Variance informed by all datapoints of Retamal et al (2009) & WCG (2009)
	Fraction of tanks with auto bypass	[fraction]	0.0						0.0	0.2	
	Fraction of tanks with manual bypass	[fraction]	0.5			0.3	0.5	0.7			
Tanks for laundry use	Rainwater yield	[kL/d]	0.078								Modelling with TANK software (Vieritz et al 2007)
	Pumping power use	[kWh/kl]	0.90	0.90	2.46						Defalt value from Retamal et al (2009). Variance informed by all datapoints of Retamal et al (2009) & WCG (2009)
	Fraction of tanks with auto bypass	[fraction]	0.63			0.20	0.63	0.80			Assumed as per tanks with toilet, laundry & external use
	Fraction of tanks with manual bypass	[fraction]	0.00								Assumed as per tanks with toilet, laundry & external use
Toilet, Laundry & external use (generic)	Rainwater yield	[kL/d]	0.171								Modelling with TANK software (Vieritz et al 2007)
	Pumping power use	[kWh/kl]	1.20	1.20	2.46						Retamal et al (2009) & WCG (2009)
	Fraction of tanks with auto bypass	[fraction]	0.63			0.20	0.63	0.80			Gardiner (2008)
	Fraction of tanks with manual bypass	[fraction]	0.00								
Tanks with auto bypass switch	Bypass controller power use	[kWh/d]	0.041						0.017	0.041	Range taken from WCG (2009) & field measurement
Tanks with manual bypass switch	Bypass controller power use	[kWh/d]	0								Assumed mechanical backup system
Tanks with tank topup	Bypass controller power use	[kWh/d]	0								Assumed mechanical backup system

APPENDIX B Inventory Summaries

Water Treatment Plants - '*Traditional Infrastructure Mix*' Scenario

			Molendinar WTP	Mudgeeraba WTP
Feed	Raw water	ML-raw/d	96.0	41.7
	pumping power use	kWh/d	10,849	4,713
WTP inputs	Power use	kWh/d	5,328	1,552
	Lime	kg/d	2,696	942
	Carbon dioxide	kg/d	2,250	1,494
	Alum Sulphate	kg/d	5,466	3,282
	Polymer (dry)	kg/d	5	0
	Polymer (liquid)	kg/d	191	0
	Sodium Hypochlorite	kg/d	3,972	2,203
	Sodium Hydroxide	kg/d	2,350	1,606
	Potassium permanganate	kg/d	26	25
	Activated carbon	kg/d	683	0
Sludge generation	Solids discharge	t-ds/d	2.0	1.3
	discharge to…		sewer	sewer
Product water	Treated water	ML-prodn/d	95.5	41.0
	Distribution power	kWh/d	13,772	

Desalination Plant - '*Future Infrastructure Mix*' Scenario

			Desal
Feed	ADWF	ML/d	298
	pumping power use	kWh/d	39,634
Treatment plant inputs	Power use	kWh/d	432,994
	Anti scalant - phoshponate based	kg/d	373
	Carbon Dioxide	kg/d	4,375
	Ferric Sulphate	kg/d	3,010
	Lime (hydrated)	kg/d	3,750
	Liquid Polymer	kg/d	372
	Sulphuric Acid	kg/d	5,337
	Sodium Bisulphite	kg/d	1,085
	Sodium Hypochlorite	kg/d	3,102
Chemical sludge	generation	t-ws/d	13.7
	disposal method		truck to landfill
	transport distance	km	50
ROC to sea	Flow	ML/d	173
Product water	Flow	ML/d	125
	pumping power use	kWh/d	50,000

Sewage Treatment Plants - *'Traditional Infrastructure Mix'* Scenario

			Beenleigh	Coombabah	Elanora	Merrimac
Sewage	ADWF	ML/d	9.8	54.0	15.1	29.4
	pumping power use	kWh/d	42,269			
	CH4 emissions	kg/d	49	270	76	147
	TN load	kg-N/d	819	3,333	1,271	1,700
	TP load	kg-P/d	157	724	247	358
	COD load	kg-COD/d	7,621	36,067	12,496	23,407
STP inputs	Power use	kWh/d	7,359	33,357	14,268	20,559
	Power generated	kWh/d	0	0	1,925	0
	Power imported from grid	kWh/d	7,359	33,357	12,343	20,559
	Ethanol	kg/d	81	0	0	0
	Alum sulphate	kg/d	1,572	0	0	0
	Ferrous chloride	kg/d	0	0	1,319	0
	Lime (dry)	kg/d	0	0	1,800	0
	Dry Polymer	kg/d	6	59	14	34
	Liquid Polymer	kg/d	29	0	0	0
STP outputs	biogas generation	ML/d	0	0	3	0
	N2O	kg/d	10	46	24	22
	NH3	kg-NH3/d	0	3	0	0
	CO2 (non-biogenic)	kg/d	284	1,770	772	1,520
	CH4	kg/d	0	0	21	0
	NOx	kg-NOx/d	0	0	11	0
	SOx	kg-SOx/d	0	0	15	0
	CO	kg-CO/d	0	0	4	0
Grit	generation	kg/d	400	1,400	151	1,000
	disposal method		truck to landfill	truck to landfill	truck to landfill	truck to landfill
	transport distance	km	10	20	50	50
Biosolids generation	generation	kg-ds/d	4,486	12,870	4,877	7,493
	moisture content	% H2O	87%	91% #	82%	87%
	disposal method		truck to farms	truck to farms	truck to farms	truck to farms
	transport distance	km	200	200	200	200
	TN	kg-N/d	318	965	262	562
	TP	kg-P/d	149	492	202	308
	C	kg-C/d	1,494	5,286	1,736	2,495
Biosolids reuse	CH4	kg/d	12.6	36.0	13.7	21.0
	CO2 (non-biogenic)	kg/d	455	1,740	469	818
	NH3	kg/d	77	234	64	136
	N2O	kg/d	5.0	15.2	4.1	8.8
	N --> WW	kg/d	19	58	16	34
	P --> WW	kg/d	7	25	10	15
	DAP offsets	kg/d	75	246	101	154
	Urea offsets	kg/d	317	953	245	550
Effluent generation	Sodium Hypochlorite use	kg/d	0	0	0	308
	Chlorine gas use	kg/d	0	435	126	0
	pumping power use	kWh/d	463	15,730	5,290	3,780
	TSS	kg/d	69	378	106	206
	TN	kg-N/d	23	159	148	88
	TP	kg-P/d	8	232	45	50
	COD	kg-COD/d	343	1890	530	1029
	chlorine	mg/L	0.0	0.5	0.1	0.4
Effluent irrigation	Flow	ML/d	1.9	10.6	3.0	5.8
	CO2 (non-biogenic)	kg/d	9	50	14	27
	NH3	kg/d	0.2	1.1	1.1	0.6
	N2O	kg/d	0.1	0.4	0.4	0.2
	N --> WW	kg/d	0	0	0	0
	P --> WW	kg/d	0	0	0	0
	DAP offsets	kg/d	4	114	22	25
	Urea offsets	kg/d	4	12	27	14
Effluent to sea	Flow	ML/d	7.9	43.4	12.2	23.6
	CO2 (non-biogenic)	kg/d	37	206	58	112
	N2O	kg/d	0.01	0.10	0.09	0.06

 # The Coombabah STP biosolids dry solids content was incorrectly set at 9%, without allowing for the moisture removal (to approx 25% dry solids) achieved by drying beds

Pimpama Water Recycling Plant - '*Future Infrastructure Mix*' Scenario

			STP	AWTP
Sewage	ADWF	ML/d	17.3	17.3
	pumping power use	kWh/d	6,672	0
	CH4 emissions	kg/d	86	0
	TN load	kg-N/d	1,126	27
	TP load	kg-P/d	235	6
	COD load	kg-COD/d	12,564	--
	TOC load	kg-C/d	--	190
Treatment inputs	Power use	kWh/d	17,499	2,244
	Power generated	kWh/d	0	0
	Power imported from grid	kWh/d	17,499	2,244
	Alum sulphate	kg/d	3,572	372
	Lime (dry)	kg/d	511	0
	Dry Polymer	kg/d	49	0
	Liquid Polymer	kg/d	0	0
	Citric Acid	kg/d	--	6
	Sodium Hypochlorite	kg/d	--	3,947
	Sulphuric Acid	kg/d	--	5
Treatment outputs	biogas generation	ML/d	0	0
	N2O	kg/d	14	0
	NH3	kg-NH3/d	0	0
	CO2 (non-biogenic)	kg/d	433	0
	CH4	kg/d	0	0
Grit	generation	kg/d	604	--
	disposal method		truck to landfill	--
	transport distance	km	15	--
Biosolids generation	generation	kg-ds/d	6,253	
	moisture content	% H2O	85%	
	disposal method		truck to farms	
	transport distance	km	200	
	TN	kg-N/d	442	
	TP	kg-P/d	232	
	C	kg-C/d	2,558	
Biosolids reuse	CH4	kg/d	17.4	
	CO2 (non-biogenic)	kg/d	788	
	NH3	kg/d	106	
	N2O	kg/d	6.9	
	N --> WW	kg-N/d	26	
	P --> WW	kg-P/d	12	
	DAP offsets	kg/d	-117	
	Urea offsets	kg/d	-434	
Effluent / product water generation	Sodium Hypochlorite use	kg/d	0	1,032
	pumping power use	kWh/d	0	7,456
	TSS	kg/d	0	0
	TN	kg-N/d	0	17
	TP	kg-P/d	0	3
	TOC	kg-C/d	0	1
	chlorine	mg/L	0	1.2
Product water to houses	Flow	ML/d	0	3.9
	CO2 (non-biogenic)	kg/d	--	7
	NH3	kg/d	--	0.08
	N2O	kg/d	--	0.03
	N --> WW	kg/d	--	0.04
	P --> WW	kg/d	--	0.01
	DAP offsets	kg/d	--	0
	Urea offsets	kg/d	--	0
Product water reuse (non res)	Flow	ML/d	0	3.3
	CO2 (non-biogenic)	kg/d	--	11
	NH3	kg/d	--	0.12
	N2O	kg/d	--	0.04
	N --> WW	kg/d	--	0
	P --> WW	kg/d	--	0
	DAP offsets	kg/d	--	-1.4
	Urea offsets	kg/d	--	-3.4
Effluent to sea	Flow	ML/d	0	9.9
	CO2 (non-biogenic)	kg/d	--	32
	N2O	kg/d	--	0.01

Coombabah Water Recycling Plant - '*Future Infrastructure Mix*' Scenario

			Coombabah AWTP
Feed	ADWF	ML/d	54
	pumping power use	kWh/d	9,513
	CH4 emissions	kg/d	0
	TN concentration	mg/L	2.95
	TP concentration	mg/L	4.30
Treatment plant inputs	Power use	kWh/d	42,209
	Power generated	kWh/d	0
	Power imported from grid	kWh/d	42,209
	Methanol	kg/d	217
	Ammonium Sulphate	kg/d	906
	Anti scalant - carboxylate based	kg/d	38
	Anti scalant - phoshponate based	kg/d	54
	Carbon Dioxide	kg/d	877
	Citric Acid	kg/d	59
	Hydrogen Peroxide	kg/d	414
	Ferric Chloride	kg/d	9,773
	Lime - hydrated	kg/d	1,545
	Dry Polymer	kg/d	13
	Liquid Polymer	kg/d	20
	Sulphuric Acid	kg/d	967
	Sodium Bisulphite	kg/d	20
	Sodium Hypochlorite	kg/d	6,362
ROC treatment	N2O emissions	kg/d	0.6
Chemical sludge	generation	t-ds/d	5.1
	moisture content	% H2O	80%
	disposal method		truck to landfill
	transport distance	km	20
	N conc	kg-N/d	0
	P concentration	kg-P/d	224
ROC to sea	Flow	ML/d	8.73
	pumping power use	kWh/d	28,391
	concentration - TN	kg-N/d	118
	concentration - TP	kg-P/d	8
	concentration - chlorine	mg/L	0.04
	N2O	kg/d	0.09
Product water to dam	Flow	ML/d	44.43
	pumping power use	kWh/d	2,544
	concentration - TN	kg-N/d	15
	concentration - TP	kg-P/d	1
	concentration - chlorine	mg/L	0.00
	N2O	kg/d	0.04

APPENDIX C Impact Factors

Freshwater Extraction

Substance	Emission Compartment	Impact Factor	
Water, cooling	Raw material	1	kL FWE / kL
Water, fresh	Raw material	1	kL FWE / kL
Water, lake	Raw material	1	kL FWE / kL
Water, mining, unspecified natural origin	Raw material	1	kL FWE / kL
Water, process	Raw material	1	kL FWE / kL
Water, reticulated supply	Raw material	1	kL FWE / kL
Water, river	Raw material	1	kL FWE / kL
Water, surface	Raw material	1	kL FWE / kL
Water, unspecified natural origin	Raw material	1	kL FWE / kL
Water, well, in ground	Raw material	1	kL FWE / kL
Water, urban rainfall	Raw material	0	kL FWE / kL
Water, stormwater	Raw material	0	kL FWE / kL

Aquatic Eutrophication Potential

Substance	Emission Compartment	Impact Factor	
Ammonia	Air	0.041	kg-PO4-e/kg
Nitrate	Air	0.003	kg-PO4-e/kg
Nitric acid	Air	0.003	kg-PO4-e/kg
Nitric oxide	Air	0.012	kg-PO4-e/kg
Nitrogen dioxide	Air	0.039	kg-PO4-e/kg
Nitrogen oxides	Air	0.039	kg-PO4-e/kg
Nitrogen, total	Air	0.013	kg-PO4-e/kg
fertiliser N	Soil	0.031	kg-PO4-e/kg
fertiliser P	Soil	0.052	kg-PO4-e/kg
manure N	Soil	0.033	kg-PO4-e/kg
manure P	Soil	0.050	kg-PO4-e/kg
Ammonium, ion	Water	0.407	kg-PO4-e/kg
BOD5	Water	0.022	kg-PO4-e/kg
COD	Water	0.022	kg-PO4-e/kg
Nitrate	Water	0.100	kg-PO4-e/kg
Nitric acid	Water	0.100	kg-PO4-e/kg
Nitrite	Water	0.100	kg-PO4-e/kg
Nitrogen	Water	0.420	kg-PO4-e/kg
Nitrogen oxides	Water	0.130	kg-PO4-e/kg
Nitrogen, organic bound	Water	0.013	kg-PO4-e/kg
Nitrogen, total	Water	0.420	kg-PO4-e/kg
Phosphate	Water	1.000	kg-PO4-e/kg
Phosphoric acid	Water	0.970	kg-PO4-e/kg
Phosphorus	Water	3.060	kg-PO4-e/kg
Phosphorus pentoxide	Water	1.340	kg-PO4-e/kg
Phosphorus, total	Water	3.060	kg-PO4-e/kg

Global Warming Potential

Substance	CAS	Emission Compartment	Impact Factor	
Carbon dioxide, biogenic	000124-38-9	Air	0	kg-CO2-e/kg
Carbon dioxide, non biogenic	000124-38-9	Air	1	kg-CO2-e/kg
Carbon dioxide, land transformation	000124-38-9	Air	1	kg-CO2-e/kg
Methane, biogenic	000074-82-8	Air	25	kg-CO2-e/kg
Methane, non biogenic	000074-82-8	Air	25	kg-CO2-e/kg
Nitrous Oxide	010024-97-2	Air	298	kg-CO2-e/kg
Ammonia	007664-41-7	Air	4	kg-CO2-e/kg
1-Propanol, 3,3,3-trifluoro-2,2-bis(trifluoromethyl)-, HFE-7100	014117-17-0	Air	297	kg-CO2-e/kg
Butane, 1,1,1,3,3-pentafluoro-, HFC-365mfc	000406-58-6	Air	794	kg-CO2-e/kg
Butane, nonafluoroethoxy, HFE-569sf2	163702-05-4	Air	59	kg-CO2-e/kg
Butane, perfluoro-	000355-25-9	Air	8,860	kg-CO2-e/kg
Butane, perfluorocyclo-, PFC-318	000115-25-3	Air	10,300	kg-CO2-e/kg
Chloroform	000067-66-3	Air	31	kg-CO2-e/kg
Dimethyl ether	000115-10-6	Air	1	kg-CO2-e/kg
Ethane, 1-chloro-1,1-difluoro-, HCFC-142b	000075-68-3	Air	2,310	kg-CO2-e/kg
Ethane, 1-chloro-2,2,2-trifluoro-(difluoromethoxy)-, HCFE-235da2	026675-46-7	Air	350	kg-CO2-e/kg
Ethane, 1,1-dichloro-1-fluoro-, HCFC-141b	001717-00-6	Air	725	kg-CO2-e/kg
Ethane, 1,1-difluoro-, HFC-152a	000075-37-6	Air	124	kg-CO2-e/kg
Ethane, 1,1,1-trichloro-, HCFC-140	000071-55-6	Air	146	kg-CO2-e/kg
Ethane, 1,1,1-trifluoro-, HFC-143a	000420-46-2	Air	4,470	kg-CO2-e/kg
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	000811-97-2	Air	1,430	kg-CO2-e/kg
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	000076-13-1	Air	6,130	kg-CO2-e/kg
Ethane, 1,1,2-trifluoro-, HFC-143	000430-66-0	Air	353	kg-CO2-e/kg
Ethane, 1,1,2,2-tetrafluoro-, HFC-134	000359-35-3	Air	1,100	kg-CO2-e/kg
Ethane, 1,2-dibromotetrafluoro-, Halon 2402	000124-73-2	Air	1,640	kg-CO2-e/kg
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	000076-14-2	Air	10,000	kg-CO2-e/kg
Ethane, 1,2-difluoro-, HFC-152	000624-72-6	Air	53	kg-CO2-e/kg
Ethane, 2-chloro-1,1,1,2-tetrafluoro-, HCFC-124	002837-89-0	Air	609	kg-CO2-e/kg
Ethane, 2,2-dichloro-1,1,1-trifluoro-, HCFC-123	000306-83-2	Air	77	kg-CO2-e/kg
Ethane, chloropentafluoro-, CFC-115	000076-15-3	Air	7,370	kg-CO2-e/kg
Ethane, fluoro-, HFC-161	000353-36-6	Air	12	kg-CO2-e/kg
Ethane, hexafluoro-, HFC-116	000076-16-4	Air	12,200	kg-CO2-e/kg
Ethane, pentafluoro-, HFC-125	000354-33-6	Air	3,500	kg-CO2-e/kg
Ether, 1,1,1-trifluoromethyl methyl-, HFE-143a	000421-14-7	Air	756	kg-CO2-e/kg
Ether, 1,1,2,2-Tetrafluoroethyl 2,2,2-trifluoroethyl-, HFE-347mcc3	000406-78-0	Air	575	kg-CO2-e/kg
Ether, 1,1,2,2-Tetrafluoroethyl 2,2,2-trifluoroethyl-, HFE-347mcf2	000406-78-0	Air	374	kg-CO2-e/kg
Ether, 1,1,2,2-Tetrafluoroethyl methyl-, HFE-254cb2	000425-88-7	Air	359	kg-CO2-e/kg
Ether, 1,1,2,3,3,3-Hexafluoropropyl methyl-, HFE-356mec3	000382-34-3	Air	101	kg-CO2-e/kg
Ether, 1,1,2,3,3,3-Hexafluoropropyl methyl-, HFE-356pcc3	000382-34-3	Air	110	kg-CO2-e/kg
Ether, 1,1,2,3,3,3-Hexafluoropropyl methyl-, HFE-356pcf2	000382-34-3	Air	265	kg-CO2-e/kg
Ether, 1,1,2,3,3,3-Hexafluoropropyl methyl-, HFE-356pcf3	000382-34-3	Air	502	kg-CO2-e/kg
Ether, 1,2,2-trifluoroethyl trifluoromethyl-, HFE-236ea2	084011-06-3	Air	989	kg-CO2-e/kg
Ether, 1,2,2-trifluoroethyl trifluoromethyl-, HFE-236fa	084011-06-3	Air	487	kg-CO2-e/kg
Ether, 2,2,3,3,3-Pentafluoropropyl methyl-, HFE-365mcf3	000378-16-5	Air	11	kg-CO2-e/kg
Ether, di(difluoromethyl), HFE-134	001691-17-4	Air	6,320	kg-CO2-e/kg
Ether, difluoromethyl 2,2,2-trifluoroethyl-, HFE-245cb2	001885-48-9	Air	708	kg-CO2-e/kg
Ether, difluoromethyl 2,2,2-trifluoroethyl-, HFE-245fa1	001885-48-9	Air	286	kg-CO2-e/kg
Ether, difluoromethyl 2,2,2-trifluoroethyl-, HFE-245fa2	001885-48-9	Air	659	kg-CO2-e/kg
Ether, ethyl 1,1,2,2-tetrafluoroethyl-, HFE-374pc2	000512-51-6	Air	557	kg-CO2-e/kg
Ether, pentafluoromethyl-, HFE-125	003822-68-2	Air	14,900	kg-CO2-e/kg

Substance	CAS	Emission Compartment	Impact Factor	
Hexane, perfluoro-	000355-42-0	Air	9,300	kg CO_2-e/kg
HFE-227EA		Air	1,540	kg CO_2-e/kg
HFE-236ca12 (HG-10)		Air	2,800	kg CO_2-e/kg
HFE-263fb2		Air	11	kg CO_2-e/kg
HFE-329mcc2		Air	919	kg CO_2-e/kg
HFE-338mcf2		Air	552	kg CO_2-e/kg
HFE-338pcc13 (HG-01)		Air	1,500	kg CO_2-e/kg
HFE-347pcf2		Air	580	kg CO_2-e/kg
HFE-43-10pccc124 (H-Galden1040x)		Air	1,870	kg CO_2-e/kg
Hydrocarbons, chlorinated		Air	11	kg CO_2-e/kg
Methane, bromo-, Halon 1001	000074-83-9	Air	5	kg CO_2-e/kg
Methane, bromochlorodifluoro-, Halon 1211	000353-59-3	Air	1,890	kg CO_2-e/kg
Methane, bromodifluoro-, Halon 1201	001511-62-2	Air	404	kg CO_2-e/kg
Methane, bromotrifluoro-, Halon 1301	000075-63-8	Air	7,140	kg CO_2-e/kg
Methane, chlorodifluoro-, HCFC-22	000075-45-6	Air	1,810	kg CO_2-e/kg
Methane, chlorotrifluoro-, CFC-13	000075-72-9	Air	14,400	kg CO_2-e/kg
Methane, dibromo-	000074-95-3	Air	2	kg CO_2-e/kg
Methane, dichloro-, HCC-30	000075-09-2	Air	9	kg CO_2-e/kg
Methane, dichlorodifluoro-, CFC-12	000075-71-8	Air	10,900	kg CO_2-e/kg
Methane, dichlorofluoro-, HCFC-21	000075-43-4	Air	151	kg CO_2-e/kg
Methane, difluoro-, HFC-32	000075-10-5	Air	675	kg CO_2-e/kg
Methane, fluoro-, HFC-41	000593-53-3	Air	92	kg CO_2-e/kg
Methane, iodotrifluoro-	002314-97-8	Air	0	kg CO_2-e/kg
Methane, monochloro-, R-40	000074-87-3	Air	13	kg CO_2-e/kg
Methane, tetrachloro-, CFC-10	000056-23-5	Air	1,400	kg CO_2-e/kg
Methane, tetrafluoro-, CFC-14	000075-73-0	Air	7,390	kg CO_2-e/kg
Methane, trichlorofluoro-, CFC-11	000075-69-4	Air	4,750	kg CO_2-e/kg
Methane, trifluoro-, HFC-23	000075-46-7	Air	14,800	kg CO_2-e/kg
Nitrogen fluoride	007783-54-2	Air	17,200	kg CO_2-e/kg
Pentane, 2,3-dihydroperfluoro-, HFC-4310mee	138495-42-8	Air	1,640	kg CO_2-e/kg
Pentane, perfluoro-	000678-26-2	Air	9,160	kg CO_2-e/kg
PFC-9-1-18		Air	7,500	kg CO_2-e/kg
PFPMIE		Air	10,300	kg CO_2-e/kg
Propane, 1,1,1,2,2,3-hexafluoro-, HFC-236cb	000677-56-5	Air	1,340	kg CO_2-e/kg
Propane, 1,1,1,2,3,3-hexafluoro-, HFC-236ea	000431-63-0	Air	1,370	kg CO_2-e/kg
Propane, 1,1,1,2,3,3,3-heptafluoro-, HFC-227ea	000431-89-0	Air	3,220	kg CO_2-e/kg
Propane, 1,1,1,3,3,3-hexafluoro-, HCFC-236fa	000690-39-1	Air	9,810	kg CO_2-e/kg
Propane, 1,1,2,2,3-pentafluoro-, HFC-245ca	000679-86-7	Air	693	kg CO_2-e/kg
Propane, 1,1,3,3-tetrafluoro-, HFC-245fa	004556-24-5	Air	1,030	kg CO_2-e/kg
Propane, 1,3-dichloro-1,1,2,2,3-pentafluoro-, HCFC-225cb	000507-55-1	Air	595	kg CO_2-e/kg
Propane, 3,3-dichloro-1,1,1,2,2-pentafluoro-, HCFC-225ca	000422-56-0	Air	122	kg CO_2-e/kg
Propane, perfluoro-	000076-19-7	Air	8,830	kg CO_2-e/kg
Sulfur hexafluoride	002551-62-4	Air	22,800	kg CO_2-e/kg
Sulphur, trifluoromethyl pentafluoride		Air	17,700	kg CO_2-e/kg

Ozone Depletion Potential

Substance	CAS	Emission Compartment	Impact Factor	
Ethane, 1-chloro-1,1-difluoro-, HCFC-142b	000075-68-3	Air	0.07	kg-CFC11-e/kg
Ethane, 1,1-dichloro-1-fluoro-, HCFC-141b	001717-00-6	Air	0.12	kg-CFC11-e/kg
Ethane, 1,1,1-trifluoro-2,2-chlorobromo-, Halon 2311	000151-67-7	Air	0.14	kg-CFC11-e/kg
Ethane, 1,1,1,2-tetrafluoro-2-bromo-, Halon 2401	000124-72-1	Air	0.25	kg-CFC11-e/kg
Ethane, 1,1,2-trichloro-	000079-00-5	Air	0.12	kg-CFC11-e/kg
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	000076-13-1	Air	1	kg-CFC11-e/kg
Ethane, 1,2-dibromotetrafluoro-, Halon 2402	000124-73-2	Air	6	kg-CFC11-e/kg
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	000076-14-2	Air	0.94	kg-CFC11-e/kg
Ethane, 2-chloro-1,1,1,2-tetrafluoro-, HCFC-124	002837-89-0	Air	0.02	kg-CFC11-e/kg
Ethane, 2,2-dichloro-1,1,1-trifluoro-, HCFC-123	000306-83-2	Air	0.02	kg-CFC11-e/kg
Ethane, chloropentafluoro-, CFC-115	000076-15-3	Air	0.44	kg-CFC11-e/kg
Hydrocarbons, chlorinated		Air	0.00617	kg-CFC11-e/kg
Methane, bromo-, Halon 1001	000074-83-9	Air	0.38	kg-CFC11-e/kg
Methane, bromochlorodifluoro-, Halon 1211	000353-59-3	Air	6	kg-CFC11-e/kg
Methane, bromodifluoro-, Halon 1201	001511-62-2	Air	1.4	kg-CFC11-e/kg
Methane, bromotrifluoro-, Halon 1301	000075-63-8	Air	12	kg-CFC11-e/kg
Methane, chlorodifluoro-, HCFC-22	000075-45-6	Air	0.05	kg-CFC11-e/kg
Methane, dibromodifluoro-, Halon 1202	000075-61-6	Air	1.3	kg-CFC11-e/kg
Methane, dichlorodifluoro-, CFC-12	000075-71-8	Air	1	kg-CFC11-e/kg
Methane, monochloro-, R-40	000074-87-3	Air	0.02	kg-CFC11-e/kg
Methane, tetrachloro-, CFC-10	000056-23-5	Air	0.73	kg-CFC11-e/kg
Methane, trichlorofluoro-, CFC-11	000075-69-4	Air	1	kg-CFC11-e/kg
Propane, 1,3-dichloro-1,1,2,2,3-pentafluoro-, HCFC-225cb	000507-55-1	Air	0.03	kg-CFC11-e/kg
Propane, 3,3-dichloro-1,1,1,2,2-pentafluoro-, HCFC-225ca	000422-56-0	Air	0.02	kg-CFC11-e/kg
Nitrous Oxide	010024-97-2	Air	0.017	kg-CFC11-e/kg

Fossil Fuel Depletion

Substance	Impact Factor	
Carbon	1.214	kg-oil-e/kg
Coal, 13.3 MJ per kg, in ground	0.317	kg-oil-e/kg
Coal, 18 MJ per kg, in ground	0.429	kg-oil-e/kg
Coal, 18.0 MJ per kg, in ground	0.429	kg-oil-e/kg
Coal, 18.5 MJ per kg, in ground	0.44	kg-oil-e/kg
Coal, 19.5 MJ per kg, in ground	0.464	kg-oil-e/kg
Coal, 20.0 MJ per kg, in ground	0.476	kg-oil-e/kg
Coal, 20.5 MJ per kg, in ground	0.488	kg-oil-e/kg
Coal, 21.5 MJ per kg, in ground	0.512	kg-oil-e/kg
Coal, 22.1 MJ per kg, in ground	0.526	kg-oil-e/kg
Coal, 22.4 MJ per kg, in ground	0.533	kg-oil-e/kg
Coal, 22.6 MJ per kg, in ground	0.538	kg-oil-e/kg
Coal, 22.8 MJ per kg, in ground	0.543	kg-oil-e/kg
Coal, 23.0 MJ per kg, in ground	0.548	kg-oil-e/kg
Coal, 24.0 MJ per kg, in ground	0.571	kg-oil-e/kg
Coal, 24.1 MJ per kg, in ground	0.574	kg-oil-e/kg
Coal, 26.4 MJ per kg, in ground	0.629	kg-oil-e/kg
Coal, 27.1 MJ per kg, in ground	0.645	kg-oil-e/kg
Coal, 28.0 MJ per kg, in ground	0.667	kg-oil-e/kg
Coal, 28.6 MJ per kg, in ground	0.681	kg-oil-e/kg
Coal, 29.0 MJ per kg, in ground	0.69	kg-oil-e/kg
Coal, 29.3 MJ per kg, in ground	0.698	kg-oil-e/kg
Coal, 30.3 MJ per kg, in ground	0.721	kg-oil-e/kg
Coal, 30.6 MJ per kg, in ground	0.729	kg-oil-e/kg
Coal, brown, 10 MJ per kg, in ground	0.238	kg-oil-e/kg
Coal, brown, 10.0 MJ per kg, in ground	0.238	kg-oil-e/kg
Coal, brown, 14.1 MJ per kg, in ground	0.336	kg-oil-e/kg
Coal, brown, 14.4 MJ per kg, in ground	0.343	kg-oil-e/kg
Coal, brown, 15 MJ per kg, in ground	0.357	kg-oil-e/kg
Coal, brown, 15.0 MJ per kg, in ground	0.357	kg-oil-e/kg
Coal, brown, 7.9 MJ per kg, in ground	0.188	kg-oil-e/kg
Coal, brown, 8 MJ per kg, in ground	0.19	kg-oil-e/kg
Coal, brown, 8.0 MJ per kg, in ground	0.19	kg-oil-e/kg
Coal, brown, 8.1 MJ per kg, in ground	0.193	kg-oil-e/kg
Coal, brown, 8.2 MJ per kg, in ground	0.195	kg-oil-e/kg
Coal, brown, 9.9 MJ per kg, in ground	0.236	kg-oil-e/kg
Coal, brown, in ground	0.236	kg-oil-e/kg
Coal, feedstock, 26.4 MJ per kg, in ground	0.629	kg-oil-e/kg
Coal, hard, unspecified, in ground	0.455	kg-oil-e/kg
Energy, from coal	0.0238	kg-oil-e/kg
Energy, from coal, brown	0.0238	kg-oil-e/kg
Energy, from gas, natural	0.0238	kg-oil-e/kg
Energy, from oil	0.0238	kg-oil-e/kg
Energy, from peat	0.0238	kg-oil-e/kg
Energy, from sulfur	0.0238	kg-oil-e/kg
Energy, unspecified	0.0238	kg-oil-e/kg
Gas, mine, off-gas, process, coal mining/kg	1.19	kg-oil-e/kg
Gas, mine, off-gas, process, coal mining/m3	0.948	kg-oil-e/kg
Gas, natural, 30.3 MJ per kg, in ground	0.721	kg-oil-e/kg
Gas, natural, 31.65 MJ per m3, in ground	0.754	kg-oil-e/kg
Gas, natural, 35 MJ per m3, in ground	0.833	kg-oil-e/kg
Gas, natural, 35.0 MJ per m3, in ground	0.833	kg-oil-e/kg
Gas, natural, 35.2 MJ per m3, in ground	0.838	kg-oil-e/kg
Gas, natural, 35.9 MJ per m3, in ground	0.855	kg-oil-e/kg
Gas, natural, 36.6 MJ per m3, in ground	0.871	kg-oil-e/kg

Substance	Impact Factor	
Gas, natural, 38.8 MJ per m3, in ground	0.924	kg-oil-e/kg
Gas, natural, 39.0 MJ per m3, in ground	0.929	kg-oil-e/kg
Gas, natural, 42.0 MJ per m3, in ground	1	kg-oil-e/kg
Gas, natural, 46.8 MJ per kg, in ground	1.11	kg-oil-e/kg
Gas, natural, 50.3 MJ per kg, in ground	1.198	kg-oil-e/kg
Gas, natural, 51.3 MJ per kg, in ground	1.221	kg-oil-e/kg
Gas, natural, feedstock, 35 MJ per m3, in ground	0.833	kg-oil-e/kg
Gas, natural, feedstock, 35.0 MJ per m3, in ground	0.833	kg-oil-e/kg
Gas, natural, feedstock, 46.8 MJ per kg, in ground	1.11	kg-oil-e/kg
Gas, natural, in ground	0.912	kg-oil-e/kg
Gas, off-gas, 35.0 MJ per m3, oil production, in ground	0.833	kg-oil-e/kg
Gas, off-gas, oil production, in ground	0.948	kg-oil-e/kg
Gas, petroleum, 35 MJ per m3, in ground	0.833	kg-oil-e/kg
Graphite, from technosphere	1.19	kg-oil-e/kg
Methane	0.855	kg-oil-e/kg
Oil, crude, 38400 MJ per m3, in ground	914	kg-oil-e/kg
Oil, crude, 41 MJ per kg, in ground	0.976	kg-oil-e/kg
Oil, crude, 41.0 MJ per kg, in ground	0.976	kg-oil-e/kg
Oil, crude, 41.9 MJ per kg, in ground	0.998	kg-oil-e/kg
Oil, crude, 42 MJ per kg, in ground	1	kg-oil-e/kg
Oil, crude, 42.6 MJ per kg, in ground	1.01	kg-oil-e/kg
Oil, crude, 42.7 MJ per kg, in ground	1.02	kg-oil-e/kg
Oil, crude, 42.8 MJ per kg, in ground	1.019	kg-oil-e/kg
Oil, crude, 43.4 MJ per kg, in ground	1.033	kg-oil-e/kg
Oil, crude, 44.0 MJ per kg, in ground	1.048	kg-oil-e/kg
Oil, crude, 44.6 MJ per kg, in ground	1.062	kg-oil-e/kg
Oil, crude, 45.0 MJ per kg, in ground	1.071	kg-oil-e/kg
Oil, crude, feedstock, 41 MJ per kg, in ground	0.976	kg-oil-e/kg
Oil, crude, feedstock, 42 MJ per kg, in ground	1	kg-oil-e/kg
Oil, crude, in ground	1.09	kg-oil-e/kg
Peat, in ground	0.236	kg-oil-e/kg

Marine Ecotoxicity Potential

		Impact Factors						
		Emission to Air		Emission to Soil		Emission to Water		
Substance	CAS	high pop / unspecified	low pop.	agricultural	industrial / unspecified	freshwater / unspecified	ocean	
1,4-Dioxane	000123-91-1	4.6E-04	5.8E-04			7.6E-04	1.9E-03	kg-1,4DCB-e (to ocean) / kg
1-Butanol	000071-36-3					5.6E-05	6.1E-04	kg-1,4DCB-e (to ocean) / kg
1-Octanol	000111-87-5	3.3E-03	4.5E-03			2.0E-03	2.5E-02	kg-1,4DCB-e (to ocean) / kg
2,4,5-T	000093-76-5				1.3E-03			kg-1,4DCB-e (to ocean) / kg
2,4-D	000094-75-7				3.3E-05			kg-1,4DCB-e (to ocean) / kg
2-Benzothiazolethiol	000149-30-4	8.5E-02	1.7E-01			1.4E-01	1.0E+00	kg-1,4DCB-e (to ocean) / kg
2-Butanol	000078-92-2					2.5E-05	2.6E-04	kg-1,4DCB-e (to ocean) / kg
2-Butenal	004170-30-3	1.6E-03	3.0E-03			1.4E-03	2.4E-02	kg-1,4DCB-e (to ocean) / kg
2-Ethoxyethyl acetate	000111-15-9	8.2E-04	1.1E-03			2.4E-04	4.3E-03	kg-1,4DCB-e (to ocean) / kg
2-Propanol	000067-63-0					1.4E-05	1.1E-04	kg-1,4DCB-e (to ocean) / kg
Abamectin	071751-41-2				6.2E-01			kg-1,4DCB-e (to ocean) / kg
Acenaphthene	000083-32-9					6.9E-04	6.7E-02	kg-1,4DCB-e (to ocean) / kg
Acephate	030560-19-1				7.7E-03			kg-1,4DCB-e (to ocean) / kg
Acetaldehyde	000075-07-0	1.5E-03	2.1E-03					kg-1,4DCB-e (to ocean) / kg
Acetic acid	000064-19-7	1.2E-03	1.6E-03			1.3E-04	3.0E-03	kg-1,4DCB-e (to ocean) / kg
Acetone	000067-64-1	7.5E-05	7.5E-05			3.5E-05	1.1E-04	kg-1,4DCB-e (to ocean) / kg
Acetonitrile	000075-05-8	1.7E-03	1.7E-03			1.5E-03	2.4E-03	kg-1,4DCB-e (to ocean) / kg
Aclonifen	074070-46-5				1.9E-02			kg-1,4DCB-e (to ocean) / kg
Acrolein	000107-02-8	3.0E+00	4.4E+00					kg-1,4DCB-e (to ocean) / kg
Acrylamide	000079-06-1	6.0E-04	1.0E-03			6.9E-05	2.8E-03	kg-1,4DCB-e (to ocean) / kg
Acrylic acid	000079-10-7	6.1E-04	9.8E-04			1.3E-04	2.7E-03	kg-1,4DCB-e (to ocean) / kg
Acrylonitrile	000107-13-1					1.8E-02	7.2E-02	kg-1,4DCB-e (to ocean) / kg
Aldehydes, unspecified	(blank)	3.5E-03	4.7E-03					kg-1,4DCB-e (to ocean) / kg
Aldicarb	000116-06-3				1.9E+00			kg-1,4DCB-e (to ocean) / kg
Aldoxycarb	001646-88-4				1.8E-02			kg-1,4DCB-e (to ocean) / kg
Allyl chloride	000107-05-1	3.5E-05	5.0E-05			7.6E-04	3.1E-02	kg-1,4DCB-e (to ocean) / kg
Allylamine	000107-11-9	9.1E-04	2.1E-03			1.4E-03	2.7E-02	kg-1,4DCB-e (to ocean) / kg
Alpha-cypermethrin	067375-30-8				3.7E+00			kg-1,4DCB-e (to ocean) / kg
Ametryn	000834-12-8				1.7E-01			kg-1,4DCB-e (to ocean) / kg
Amitraz	033089-61-1				3.4E-02			kg-1,4DCB-e (to ocean) / kg
Aniline	000062-53-3	1.4E-03	4.6E-03			5.3E-03	4.5E-02	kg-1,4DCB-e (to ocean) / kg
Anthracene	000120-12-7	9.9E-03	1.3E-02		5.4E-03	1.8E-04	8.6E-02	kg-1,4DCB-e (to ocean) / kg
Antimony	007440-36-0	1.0E+01	1.4E+01	1.0E+00	2.0E+00	1.5E+01	2.9E+01	kg-1,4DCB-e (to ocean) / kg
Arsenic	007440-38-2	1.6E+01	2.3E+01	5.0E-02	7.6E-02			kg-1,4DCB-e (to ocean) / kg
Arsenic, ion	017428-41-0					1.5E+01	4.8E+01	kg-1,4DCB-e (to ocean) / kg
Atrazine	001912-24-9				4.1E+00			kg-1,4DCB-e (to ocean) / kg
Azadirachtin	011141-17-6				4.4E-02			kg-1,4DCB-e (to ocean) / kg
Azinphos-methyl	000086-50-0				2.3E-02			kg-1,4DCB-e (to ocean) / kg
Barium	007440-39-3	1.4E+00	1.8E+00	2.5E-01	4.8E-01	2.8E+00	3.7E+00	kg-1,4DCB-e (to ocean) / kg
Bendiocarb	022781-23-3				1.2E-02			kg-1,4DCB-e (to ocean) / kg
Benomyl	017804-35-2				1.4E-04			kg-1,4DCB-e (to ocean) / kg
Bentazone	025057-89-0				5.6E-04			kg-1,4DCB-e (to ocean) / kg
Benzaldehyde	000100-52-7	4.1E-03	5.4E-03			2.4E-03	2.7E-02	kg-1,4DCB-e (to ocean) / kg
Benzenamine, 4-methyl-	000106-49-0	4.2E-02	1.7E-01			1.2E+00	4.6E+00	kg-1,4DCB-e (to ocean) / kg
Benzene	000071-43-2	8.3E-04	8.6E-04			1.3E-03	2.3E-02	kg-1,4DCB-e (to ocean) / kg
Benzene, 1,2,4-trichloro-	000120-82-1	5.7E-01	5.8E-01			6.6E-01	3.4E+00	kg-1,4DCB-e (to ocean) / kg
Benzene, 1,2-dichloro-	000095-50-1	1.5E-01	1.5E-01			1.6E-01	7.6E-01	kg-1,4DCB-e (to ocean) / kg
Benzene, 1,3,5-trimethyl-	000108-67-8					2.9E-03	1.0E-01	kg-1,4DCB-e (to ocean) / kg
Benzene, 1,3-dichloro-	000541-73-1	5.1E-02	5.2E-02			6.7E-02	5.2E-01	kg-1,4DCB-e (to ocean) / kg
Benzene, 1,3-dinitro-	000099-65-0	2.6E-01	2.9E-01			1.2E-01	4.5E-01	kg-1,4DCB-e (to ocean) / kg
Benzene, 1,4-dichloro-	000106-46-7	1.9E-01	1.9E-01			2.1E-01	1.0E+00	kg-1,4DCB-e (to ocean) / kg
Benzene, 1,4-dinitro-	000100-25-4	3.0E+00	3.0E+00			2.8E+00	4.6E+00	kg-1,4DCB-e (to ocean) / kg
Benzene, chloro-	000108-90-7					5.8E-02	6.3E-01	kg-1,4DCB-e (to ocean) / kg
Benzene, ethyl-	000100-41-4	1.9E-04	2.3E-04			1.5E-03	5.2E-02	kg-1,4DCB-e (to ocean) / kg
Benzene, hexachloro-	000118-74-1	1.1E+02	1.1E+02					kg-1,4DCB-e (to ocean) / kg
Benzene, pentachloro-	000608-93-5	1.9E+01	1.9E+01					kg-1,4DCB-e (to ocean) / kg
Benzo(a)pyrene	000050-32-8	6.5E-04	2.7E-03					kg-1,4DCB-e (to ocean) / kg
Benzyl chloride	000100-44-7	6.1E-03	6.5E-03			4.3E-03	4.8E-02	kg-1,4DCB-e (to ocean) / kg
Beryllium	007440-41-7	2.4E+02	2.9E+02	6.0E+01	1.2E+02	4.5E+02	5.5E+02	kg-1,4DCB-e (to ocean) / kg
Bifenox	042576-02-3				8.1E-02			kg-1,4DCB-e (to ocean) / kg
Bifenthrin	082657-04-3				5.0E-01			kg-1,4DCB-e (to ocean) / kg
Bitertanol	055179-31-2				1.2E-03			kg-1,4DCB-e (to ocean) / kg
Botran	000099-30-9				6.2E-02			kg-1,4DCB-e (to ocean) / kg
Bromacil	000314-40-9				1.0E-03			kg-1,4DCB-e (to ocean) / kg
Bromine	007726-95-6	5.5E+00		3.1E+00	3.3E+00	4.7E+00	1.1E+01	kg-1,4DCB-e (to ocean) / kg
Bromoform	000075-25-2	2.6E-01	2.6E-01					kg-1,4DCB-e (to ocean) / kg
Bromoxynil	001689-84-5				2.2E-01			kg-1,4DCB-e (to ocean) / kg
Bromuconazole	116255-48-2				8.5E-02			kg-1,4DCB-e (to ocean) / kg
Butadiene, hexachloro-	000087-68-3	3.4E+00	3.4E+00					kg-1,4DCB-e (to ocean) / kg
Butylate	002008-41-5				7.9E-03			kg-1,4DCB-e (to ocean) / kg
Cadmium	007440-43-9	2.8E+01	4.0E+01	6.7E-02	3.4E-01			kg-1,4DCB-e (to ocean) / kg
Cadmium, ion	022537-48-0					7.1E+00	8.7E+01	kg-1,4DCB-e (to ocean) / kg
Captan	000133-06-2				5.3E-06			kg-1,4DCB-e (to ocean) / kg
Carbamic acid, butyl-, 3-iodo-2-propynyl ester	055406-53-6	3.1E-02	5.1E-02			1.2E-02	3.7E-01	kg-1,4DCB-e (to ocean) / kg
Carbaryl	000063-25-2				2.0E-04			kg-1,4DCB-e (to ocean) / kg
Carbendazim	010605-21-7				3.6E-01			kg-1,4DCB-e (to ocean) / kg
Carbetamide	016118-49-3				1.7E-04			kg-1,4DCB-e (to ocean) / kg

		Impact Factors						
		Emission to Air		Emission to Soil		Emission to Water		
Substance	CAS	high pop / unspecified	low pop.	agricultural	industrial / unspecified	freshwater / unspecified	ocean	
Carbofuran	001563-66-2				1.6E-01			kg-1,4DCB-e (to ocean) / kg
Carbon disulfide	000075-15-0	1.2E-03	1.3E-03					kg-1,4DCB-e (to ocean) / kg
Carboxin	005234-68-4				3.5E-03			kg-1,4DCB-e (to ocean) / kg
Carboxylic acids, unspecified	(blank)					1.1E-04	2.3E-03	kg-1,4DCB-e (to ocean) / kg
Chlorfenvinphos	000470-90-6				4.0E-01			kg-1,4DCB-e (to ocean) / kg
Chloridazon	001698-60-8				1.9E-02			kg-1,4DCB-e (to ocean) / kg
Chlorine	007782-50-5	3.5E+00				3.1E+00	7.1E+00	kg-1,4DCB-e (to ocean) / kg
Chlormequat chloride	000999-81-5				7.4E-04			kg-1,4DCB-e (to ocean) / kg
Chloroform	000067-66-3	5.2E-02	5.2E-02			5.5E-02	1.6E-01	kg-1,4DCB-e (to ocean) / kg
Chloropicrin	000076-06-2				1.1E+01			kg-1,4DCB-e (to ocean) / kg
Chlorothalonil	001897-45-6				4.2E+00			kg-1,4DCB-e (to ocean) / kg
Chlorotoluron	015545-48-9				7.4E-02			kg-1,4DCB-e (to ocean) / kg
Chlorpropham	000101-21-3				2.3E-02			kg-1,4DCB-e (to ocean) / kg
Chlorpyrifos	002921-88-2				2.7E-01			kg-1,4DCB-e (to ocean) / kg
Chlorsulfuron	064902-72-3				2.7E-02			kg-1,4DCB-e (to ocean) / kg
Chromium VI	018540-29-9	3.2E+00	4.6E+00	1.3E-03	1.8E-03	6.7E-01	9.9E+00	kg-1,4DCB-e (to ocean) / kg
Clopyralid	001702-17-6				2.8E-03			kg-1,4DCB-e (to ocean) / kg
Cloquintocet-mexyl	099607-70-2				1.4E-05			kg-1,4DCB-e (to ocean) / kg
Cobalt	007440-48-4	6.7E+00	8.2E+00	1.7E+00	3.3E+00	9.4E+00	1.8E+01	kg-1,4DCB-e (to ocean) / kg
Copper	007440-50-8	9.8E+01	1.4E+02	1.8E-01	5.6E-01			kg-1,4DCB-e (to ocean) / kg
Cumene	000098-82-8	2.2E-04	2.5E-04			1.9E-03	7.4E-02	kg-1,4DCB-e (to ocean) / kg
Cyanazine	021725-46-2				1.0E-02			kg-1,4DCB-e (to ocean) / kg
Cyanide	000057-12-5	5.7E-01	5.8E-01			3.4E-01	9.2E-01	kg-1,4DCB-e (to ocean) / kg
Cycloate	001134-23-2				1.8E-02			kg-1,4DCB-e (to ocean) / kg
Cyclohexane	000110-82-7					2.4E-03	5.0E-02	kg-1,4DCB-e (to ocean) / kg
Cyclohexanol	000108-93-0					5.1E-05	8.8E-04	kg-1,4DCB-e (to ocean) / kg
Cyclohexylamine	000108-91-8	1.3E-03	3.0E-03			4.5E-03	3.5E-02	kg-1,4DCB-e (to ocean) / kg
Cyclopentadiene, hexachloro-	000077-47-4	2.7E-06	2.7E-06					kg-1,4DCB-e (to ocean) / kg
Cycloxydim	101205-02-1				4.1E-05			kg-1,4DCB-e (to ocean) / kg
Cyfluthrin	068359-37-5				9.2E-02			kg-1,4DCB-e (to ocean) / kg
Cymoxanil	057966-95-7				7.6E-05			kg-1,4DCB-e (to ocean) / kg
Cypermethrin	052315-07-8				1.3E+02			kg-1,4DCB-e (to ocean) / kg
Cyromazine	066215-27-8				3.5E-01			kg-1,4DCB-e (to ocean) / kg
Daminozide	001596-84-5				2.9E-05			kg-1,4DCB-e (to ocean) / kg
DDAC	007173-51-5				1.6E-04			kg-1,4DCB-e (to ocean) / kg
Deltamethrin	052918-63-5				8.9E-01			kg-1,4DCB-e (to ocean) / kg
Desmedipham	013684-56-5				1.6E-07			kg-1,4DCB-e (to ocean) / kg
Desmetryn	001014-69-3				8.6E-02			kg-1,4DCB-e (to ocean) / kg
Diazinon	000333-41-5				5.6E-01			kg-1,4DCB-e (to ocean) / kg
Dibenzofuran	000132-64-9	1.4E-01	1.6E-01			1.5E-01	9.8E-01	kg-1,4DCB-e (to ocean) / kg
Dicamba	001918-00-9				9.0E-03			kg-1,4DCB-e (to ocean) / kg
Dichlobenil	001194-65-6				4.9E-01			kg-1,4DCB-e (to ocean) / kg
Dichlorvos	000062-73-7				1.2E-02			kg-1,4DCB-e (to ocean) / kg
Dicofol	000115-32-2				2.2E-03			kg-1,4DCB-e (to ocean) / kg
Dicyclopentadiene	000077-73-6	1.6E-05	6.1E-05			5.6E-03	2.0E-01	kg-1,4DCB-e (to ocean) / kg
Diethanolamine	000111-42-2	8.3E-05	2.8E-04			9.4E-05	2.5E-03	kg-1,4DCB-e (to ocean) / kg
Difenoconazole	119446-68-3				1.2E-02			kg-1,4DCB-e (to ocean) / kg
Difenzoquat	043222-48-6				1.6E-03			kg-1,4DCB-e (to ocean) / kg
Diflubenzuron	035367-38-5				1.5E-01			kg-1,4DCB-e (to ocean) / kg
Dimethipin	055290-64-7				2.7E-03			kg-1,4DCB-e (to ocean) / kg
Dimethoate	000060-51-5				5.6E-02			kg-1,4DCB-e (to ocean) / kg
Dimethylamine	000124-40-3	7.3E-05	1.9E-04			3.9E-05	2.5E-03	kg-1,4DCB-e (to ocean) / kg
Dinoseb	000088-85-7				3.3E+00			kg-1,4DCB-e (to ocean) / kg
Dinoterb	001420-07-1				2.3E+00			kg-1,4DCB-e (to ocean) / kg
Diphenamid	000957-51-7				3.8E-04			kg-1,4DCB-e (to ocean) / kg
Dipropylthiocarbamic acid S-ethyl ester	000759-94-4	4.8E-03	8.5E-03		4.4E-03	1.2E-02	1.9E-01	kg-1,4DCB-e (to ocean) / kg
Diquat dibromide	000085-00-7				8.9E-03			kg-1,4DCB-e (to ocean) / kg
Disodium acid methane arsenate	000144-21-8				3.6E-04			kg-1,4DCB-e (to ocean) / kg
Disulfoton	000298-04-4				3.7E-02			kg-1,4DCB-e (to ocean) / kg
Dithianon	003347-22-6				1.0E-01			kg-1,4DCB-e (to ocean) / kg
Diuron	000330-54-1				3.0E-01			kg-1,4DCB-e (to ocean) / kg
DNOC	000534-52-1				6.1E-03			kg-1,4DCB-e (to ocean) / kg
Dodine	002439-10-3				1.5E-03			kg-1,4DCB-e (to ocean) / kg
EDTA	000060-00-4					7.1E-05	3.1E-03	kg-1,4DCB-e (to ocean) / kg
Endosulfan	000115-29-7				1.3E-01			kg-1,4DCB-e (to ocean) / kg
Endothall	000145-73-3				4.8E-05			kg-1,4DCB-e (to ocean) / kg
Epichlorohydrin	000106-89-8	1.8E-02	1.8E-02					kg-1,4DCB-e (to ocean) / kg
Epoxiconazole	106325-08-0				1.4E+00			kg-1,4DCB-e (to ocean) / kg
Esfenvalerate	066230-04-4				2.6E+02			kg-1,4DCB-e (to ocean) / kg
Ethane, 1,1,1-trichloro-, HCFC-140	000071-55-6	3.6E-02	3.6E-02			3.7E-02	9.6E-02	kg-1,4DCB-e (to ocean) / kg
Ethane, 1,1,2,2-tetrachloro-	000079-34-5	9.2E-03	9.2E-03			9.0E-03	2.1E-02	kg-1,4DCB-e (to ocean) / kg
Ethane, 1,1,2-trichloro-	000079-00-5	8.5E-02	8.6E-02					kg-1,4DCB-e (to ocean) / kg
Ethane, 1,2-dibromo-	000106-93-4	1.9E-01	1.9E-01			1.9E-01	4.8E-01	kg-1,4DCB-e (to ocean) / kg
Ethane, 1,2-dichloro-	000107-06-2	5.0E-02	5.1E-02			5.2E-02	1.1E-01	kg-1,4DCB-e (to ocean) / kg
Ethane, hexachloro-	000067-72-1					2.3E+00	3.9E+00	kg-1,4DCB-e (to ocean) / kg
Ethane, pentachloro-	000076-01-7	1.4E-03	1.4E-03					kg-1,4DCB-e (to ocean) / kg
Ethanol	000064-17-5	1.8E-05	2.0E-05					kg-1,4DCB-e (to ocean) / kg

		Impact Factors						
		Emission to Air		Emission to Soil		Emission to Water		
Substance	CAS	high pop / unspecified	low pop.	agricultural	industrial / unspecified	freshwater / unspecified	ocean	
Ethanol, 2-butoxy-	000111-76-2					2.7E-05	5.6E-04	kg-1,4DCB-e (to ocean) / kg
Ethene, tetrachloro-	000127-18-4	7.8E-02	7.8E-02			1.1E-01	1.0E+00	kg-1,4DCB-e (to ocean) / kg
Ethene, trichloro-	000079-01-6	1.1E-03	1.1E-03			4.6E-03	1.1E-01	kg-1,4DCB-e (to ocean) / kg
Ethephon	016672-87-0				2.3E-04			kg-1,4DCB-e (to ocean) / kg
Ethion	000563-12-2				9.1E-04			kg-1,4DCB-e (to ocean) / kg
Ethofumesate	026225-79-6				2.6E-03			kg-1,4DCB-e (to ocean) / kg
Ethoprop	013194-48-4				4.5E+00			kg-1,4DCB-e (to ocean) / kg
Ethylene diamine	000107-15-3	2.7E-04	7.5E-04			2.1E-04	4.8E-03	kg-1,4DCB-e (to ocean) / kg
Ethylene glycol	000107-21-1					5.1E-06	5.8E-05	kg-1,4DCB-e (to ocean) / kg
Ethylene oxide	000075-21-8	5.1E-03	5.1E-03			4.6E-03	8.3E-03	kg-1,4DCB-e (to ocean) / kg
Etridiazole	002593-15-9				8.4E-02			kg-1,4DCB-e (to ocean) / kg
Fenamiphos	022224-92-6				2.2E-01			kg-1,4DCB-e (to ocean) / kg
Fenarimol	060168-88-9				2.5E-01			kg-1,4DCB-e (to ocean) / kg
Fenbuconazole	114369-43-6				1.2E-01			kg-1,4DCB-e (to ocean) / kg
Fenbutatin oxide	013356-08-6				2.6E-08			kg-1,4DCB-e (to ocean) / kg
Fenitrothion	000122-14-5				5.1E-02			kg-1,4DCB-e (to ocean) / kg
Fenpiclonil	074738-17-3				2.4E-02			kg-1,4DCB-e (to ocean) / kg
Fenpropathrin	039515-41-8				5.5E+00			kg-1,4DCB-e (to ocean) / kg
Fenpropimorph	067306-03-0				8.0E-03			kg-1,4DCB-e (to ocean) / kg
Fentin acetate	000900-95-8				3.2E-01			kg-1,4DCB-e (to ocean) / kg
Fentin hydroxide	000076-87-9				1.5E-01			kg-1,4DCB-e (to ocean) / kg
Fenvalerate	051630-58-1				5.3E-02			kg-1,4DCB-e (to ocean) / kg
Ferbam	014484-64-1				2.4E-01			kg-1,4DCB-e (to ocean) / kg
Fluazifop-P-butyl	079241-46-6				1.5E-02			kg-1,4DCB-e (to ocean) / kg
Fluazinam	079622-59-6				5.8E+00			kg-1,4DCB-e (to ocean) / kg
Fluometuron	002164-17-2				9.2E-03			kg-1,4DCB-e (to ocean) / kg
Fluoranthene	000206-44-0	1.8E-01	3.2E-01			1.1E-01	3.1E+00	kg-1,4DCB-e (to ocean) / kg
Fluorochloridone	061213-25-0				1.9E-02			kg-1,4DCB-e (to ocean) / kg
Flutolanil	066332-96-5				7.2E-04			kg-1,4DCB-e (to ocean) / kg
Folpet	000133-07-3				1.1E+01			kg-1,4DCB-e (to ocean) / kg
Fomesafen	072178-02-0				1.1E-03			kg-1,4DCB-e (to ocean) / kg
Fonofos	000944-22-9				4.8E-01			kg-1,4DCB-e (to ocean) / kg
Formaldehyde	000050-00-0	4.2E-03	5.7E-03			7.1E-04	1.4E-02	kg-1,4DCB-e (to ocean) / kg
Formic acid	000064-18-6					8.3E-05	1.7E-03	kg-1,4DCB-e (to ocean) / kg
Fosetyl-aluminium	039148-24-8				8.7E-04			kg-1,4DCB-e (to ocean) / kg
Fuberidazole	003878-19-1				7.9E-03			kg-1,4DCB-e (to ocean) / kg
Glufosinate ammonium	077182-82-2				2.3E-03			kg-1,4DCB-e (to ocean) / kg
Glyphosate	001071-83-6				4.9E-05			kg-1,4DCB-e (to ocean) / kg
Heptane	000142-82-5	3.2E-08	3.8E-08					kg-1,4DCB-e (to ocean) / kg
Heptenophos	023560-59-0				1.7E-02			kg-1,4DCB-e (to ocean) / kg
Hexane	000110-54-3	2.0E-06	2.3E-06					kg-1,4DCB-e (to ocean) / kg
Hexazinone	051235-04-2				2.0E-02			kg-1,4DCB-e (to ocean) / kg
Hexythiazox	078587-05-0				4.5E-04			kg-1,4DCB-e (to ocean) / kg
Hydrazine	000302-01-2					7.6E-02	1.2E+00	kg-1,4DCB-e (to ocean) / kg
Hydrazine, methyl-	000060-34-4	1.2E-01	3.1E-01					kg-1,4DCB-e (to ocean) / kg
Hydrocarbons, aliphatic, alkanes, cyclic	(blank)	9.6E-06	2.3E-05					kg-1,4DCB-e (to ocean) / kg
Hydrocarbons, aromatic	(blank)	8.0E-04	8.3E-04			8.4E-02	2.3E+00	kg-1,4DCB-e (to ocean) / kg
Hydrocarbons, chlorinated	(blank)	1.2E-01						kg-1,4DCB-e (to ocean) / kg
Hydroquinone	000123-31-9	3.8E-03	7.5E-03			6.2E-05	3.0E-02	kg-1,4DCB-e (to ocean) / kg
Hymexazol	010004-44-1				5.5E-04			kg-1,4DCB-e (to ocean) / kg
Imazaquin	081335-37-7				1.4E-04			kg-1,4DCB-e (to ocean) / kg
Ioxynil	001689-83-4				1.8E-02			kg-1,4DCB-e (to ocean) / kg
Iprodion	036734-19-7				1.0E-05			kg-1,4DCB-e (to ocean) / kg
Isofenphos	025311-71-1				1.2E-02			kg-1,4DCB-e (to ocean) / kg
Isoproturon	034123-59-6				4.1E-01			kg-1,4DCB-e (to ocean) / kg
Lambda-cyhalothrin	091465-08-6				4.8E+00			kg-1,4DCB-e (to ocean) / kg
Lead	007439-92-1	1.6E+00	2.2E+00	4.1E-04	4.9E-04	2.9E-01	4.9E+00	kg-1,4DCB-e (to ocean) / kg
Lindane	000058-89-9				5.7E+00			kg-1,4DCB-e (to ocean) / kg
Linuron	000330-55-2				5.1E-01			kg-1,4DCB-e (to ocean) / kg
Malathion	000121-75-5				2.3E-02			kg-1,4DCB-e (to ocean) / kg
Maleic anhydride	000108-31-6	2.7E-08	4.0E-08			3.0E-13	8.7E-08	kg-1,4DCB-e (to ocean) / kg
Maleic hydrazide	000123-33-1				3.5E-04			kg-1,4DCB-e (to ocean) / kg
Mancozeb	008018-01-7				3.4E-05			kg-1,4DCB-e (to ocean) / kg
Maneb	012427-38-2				5.3E-03			kg-1,4DCB-e (to ocean) / kg
Manganese	007439-96-5	1.6E+00	2.3E+00	2.9E-03	3.2E-03	1.4E+00	5.3E+00	kg-1,4DCB-e (to ocean) / kg
MCPA	000094-74-6				2.3E-04			kg-1,4DCB-e (to ocean) / kg
MCPB	000094-81-5				5.0E-04			kg-1,4DCB-e (to ocean) / kg
m-Cresol	000108-39-4	1.5E-03	3.8E-03		1.7E-03	4.1E-03	4.3E-02	kg-1,4DCB-e (to ocean) / kg
Mecoprop	000093-65-2				2.5E-04			kg-1,4DCB-e (to ocean) / kg
Mepiquat chloride	024307-26-4				2.5E-04			kg-1,4DCB-e (to ocean) / kg
Mercury	007439-97-6	5.9E+02	6.6E+02	3.1E+01	3.2E+01	7.5E+01	9.5E+02	kg-1,4DCB-e (to ocean) / kg
Metalaxil	057837-19-1				1.1E-02			kg-1,4DCB-e (to ocean) / kg
Metamitron	041394-05-2				7.0E-04			kg-1,4DCB-e (to ocean) / kg
Metam-sodium	000137-42-8				1.1E-01			kg-1,4DCB-e (to ocean) / kg
Metazachlor	067129-08-2				4.1E-02			kg-1,4DCB-e (to ocean) / kg
Methabenzthiazuron	018691-97-9				1.3E-01			kg-1,4DCB-e (to ocean) / kg
Methacrylic acid, methyl ester	000080-62-6	1.3E-04	2.0E-04			4.1E-04	7.3E-03	kg-1,4DCB-e (to ocean) / kg
Methamidophos	010265-92-6				8.3E-02			kg-1,4DCB-e (to ocean) / kg
Methane, bromo-, Halon 1001	000074-83-9	1.0E-01	1.0E-01					kg-1,4DCB-e (to ocean) / kg

		Impact Factors						
		Emission to Air		Emission to Soil		Emission to Water		
Substance	CAS	high pop / unspecified	low pop.	agricultural	industrial / unspecified	freshwater / unspecified	ocean	
Methane, dichloro-, HCC-30	000075-09-2	3.3E-03	3.3E-03			3.2E-03	1.2E-02	kg-1,4DCB-e (to ocean) / kg
Methane, tetrachloro-, CFC-10	000056-23-5	5.4E-01	5.4E-01			5.6E-01	1.0E+00	kg-1,4DCB-e (to ocean) / kg
Methanol	000067-56-1	9.8E-05	1.0E-04			2.0E-05	1.5E-04	kg-1,4DCB-e (to ocean) / kg
Methidathion	000950-37-8				4.6E-03			kg-1,4DCB-e (to ocean) / kg
Methiocarb	002032-65-7				2.0E+00			kg-1,4DCB-e (to ocean) / kg
Methomyl	016752-77-5				1.8E+00			kg-1,4DCB-e (to ocean) / kg
Methoxychlor	000072-43-5				2.2E-03			kg-1,4DCB-e (to ocean) / kg
Methyl acrylate	000096-33-3	5.0E-03	6.2E-03			4.6E-03	5.8E-02	kg-1,4DCB-e (to ocean) / kg
Methyl ethyl ketone	000078-93-3					5.2E-05	2.1E-04	kg-1,4DCB-e (to ocean) / kg
Metiram	009006-42-2				6.8E-02			kg-1,4DCB-e (to ocean) / kg
Metobromuron	003060-89-7				2.6E-01			kg-1,4DCB-e (to ocean) / kg
Metolachlor	051218-45-2				6.3E-01			kg-1,4DCB-e (to ocean) / kg
Metribuzin	021087-64-9				5.2E-03			kg-1,4DCB-e (to ocean) / kg
Metsulfuron-methyl	074223-64-6				1.2E+00			kg-1,4DCB-e (to ocean) / kg
Mevinfos	007786-34-7				1.2E-02			kg-1,4DCB-e (to ocean) / kg
Molinate	002212-67-1				5.6E-03			kg-1,4DCB-e (to ocean) / kg
Molybdenum	007439-98-7	2.0E-01	2.8E-01	6.6E-03	1.2E-02	5.1E-01	6.4E-01	kg-1,4DCB-e (to ocean) / kg
Monochloramine	(blank)	9.6E-01				1.1E-01	2.5E+00	kg-1,4DCB-e (to ocean) / kg
Monoethanolamine	000141-43-5	3.2E-04	6.9E-04					kg-1,4DCB-e (to ocean) / kg
Monolinuron	001746-81-2				1.5E-01			kg-1,4DCB-e (to ocean) / kg
Monosodium acid methanearsonate	002163-80-6				4.3E-04			kg-1,4DCB-e (to ocean) / kg
m-Xylene	000108-38-3	1.4E-04	2.2E-04			5.5E-03	1.8E-01	kg-1,4DCB-e (to ocean) / kg
Myclobutanil	088671-89-0				8.7E-03			kg-1,4DCB-e (to ocean) / kg
Naled	000300-76-5				1.1E+00			kg-1,4DCB-e (to ocean) / kg
Naphthalene	000091-20-3	3.0E-03	4.5E-03			7.2E-03	2.0E-01	kg-1,4DCB-e (to ocean) / kg
Napropamide	015299-99-7				3.6E-09			kg-1,4DCB-e (to ocean) / kg
Nickel	007440-02-0	8.8E+01	1.3E+02	4.4E-01	3.1E+00			kg-1,4DCB-e (to ocean) / kg
Nickel, ion	014701-22-5					9.6E+01	2.7E+02	kg-1,4DCB-e (to ocean) / kg
Nitrilotriacetic acid	000139-13-9	8.3E-05	2.2E-04			4.1E-05	1.8E-03	kg-1,4DCB-e (to ocean) / kg
Nitrobenzene	000098-95-3	1.4E-01	1.4E-01			1.2E-01	2.0E-01	kg-1,4DCB-e (to ocean) / kg
Nitroglycerin	000055-63-0	3.1E-02	4.4E-02			6.0E-03	9.8E-02	kg-1,4DCB-e (to ocean) / kg
N-Nitrosodiethylamine	000055-18-5	2.7E-03	3.9E-03					kg-1,4DCB-e (to ocean) / kg
Norflurazon	027314-13-2				1.5E-02			kg-1,4DCB-e (to ocean) / kg
o-Cresol	000095-48-7	9.7E-04	2.0E-03			7.4E-04	1.7E-02	kg-1,4DCB-e (to ocean) / kg
Oryzalin	019044-88-3				2.0E-02			kg-1,4DCB-e (to ocean) / kg
o-Toluidine	000095-53-4	2.1E-09	8.6E-09			1.8E-04	9.5E-03	kg-1,4DCB-e (to ocean) / kg
Oxadixyl	077732-09-3				2.3E-04			kg-1,4DCB-e (to ocean) / kg
Oxamyl	023135-22-0				4.6E-04			kg-1,4DCB-e (to ocean) / kg
Oxydemeton-methyl	000301-12-2				7.8E-03			kg-1,4DCB-e (to ocean) / kg
Oxydiazon	019666-30-9				6.2E-03			kg-1,4DCB-e (to ocean) / kg
Oxyfluorfen	042874-03-3				1.0E-01			kg-1,4DCB-e (to ocean) / kg
o-Xylene	000095-47-6	4.0E-04	5.5E-04			6.1E-03	2.0E-01	kg-1,4DCB-e (to ocean) / kg
Paclobutrazol	076738-62-0				2.0E-03			kg-1,4DCB-e (to ocean) / kg
PAH, polycyclic aromatic hydrocarbons	130498-29-2	1.1E-02	1.9E-02			7.1E-03	2.0E-01	kg-1,4DCB-e (to ocean) / kg
Parathion	000056-38-2				6.7E-02			kg-1,4DCB-e (to ocean) / kg
Parathion, methyl	000298-00-0				1.3E-02			kg-1,4DCB-e (to ocean) / kg
p-Cresol	000106-44-5	1.7E-04	3.8E-04			1.1E-05	3.4E-03	kg-1,4DCB-e (to ocean) / kg
Pendimethalin	040487-42-1				3.5E-01			kg-1,4DCB-e (to ocean) / kg
Phenanthrene	000085-01-8	1.2E-02	1.6E-02			1.7E-03	1.1E-01	kg-1,4DCB-e (to ocean) / kg
Phenmedipham	013684-63-4				6.5E-09			kg-1,4DCB-e (to ocean) / kg
Phenol	000108-95-2	2.7E-04	4.9E-04			3.6E-05	2.5E-03	kg-1,4DCB-e (to ocean) / kg
Phenol, 2,4,5-trichloro-	000095-95-4	2.1E-02	2.2E-02			7.8E-04	4.5E-02	kg-1,4DCB-e (to ocean) / kg
Phenol, 2,4,6-trichloro-	000088-06-2	6.9E-03	9.9E-03			2.2E-04	2.1E-02	kg-1,4DCB-e (to ocean) / kg
Phenol, 2,4-dichloro-	000120-83-2	4.1E-04	4.5E-04			2.2E-06	1.1E-03	kg-1,4DCB-e (to ocean) / kg
Phenol, 2,4-dimethyl-	000105-67-9	1.3E-03	3.5E-03			2.2E-03	5.0E-02	kg-1,4DCB-e (to ocean) / kg
Phenol, 2,4-dinitro-	000051-28-5	7.7E-02	9.5E-02			5.1E-02	1.9E-01	kg-1,4DCB-e (to ocean) / kg
Phenol, 2-nitro-	000088-75-5	1.1E-01	1.1E-01			6.2E-02	1.8E-01	kg-1,4DCB-e (to ocean) / kg
Phenol, 4-nitro-	000100-02-7	2.6E-05	2.9E-05			1.3E-04	9.6E-03	kg-1,4DCB-e (to ocean) / kg
Phenol, pentachloro-	000087-86-5	2.3E-02	3.4E-02					kg-1,4DCB-e (to ocean) / kg
Phorate	000298-02-2				6.9E-02			kg-1,4DCB-e (to ocean) / kg
Phosmet	000732-11-6				5.9E-03			kg-1,4DCB-e (to ocean) / kg
Phosphorus	007723-14-0	1.0E+01		6.4E+00	6.5E+00	6.7E+00	1.9E+01	kg-1,4DCB-e (to ocean) / kg
Phthalate, butyl-benzyl-	000085-68-7					1.3E-02	2.5E-01	kg-1,4DCB-e (to ocean) / kg
Phthalate, dibutyl-	000084-74-2					5.6E-02	8.4E-01	kg-1,4DCB-e (to ocean) / kg
Phthalate, dimethyl-	000131-11-3					3.9E-04	8.0E-03	kg-1,4DCB-e (to ocean) / kg
Phthalate, dioctyl-	000117-81-7					6.7E-03	1.3E-01	kg-1,4DCB-e (to ocean) / kg
Picloram	001918-02-1				4.8E-03			kg-1,4DCB-e (to ocean) / kg
Pirimicarb	023103-98-2				1.8E-03			kg-1,4DCB-e (to ocean) / kg
Pirimiphos methyl	029232-93-7				6.4E-02			kg-1,4DCB-e (to ocean) / kg
p-Nitroaniline	000100-01-6	2.8E-02	4.3E-02			1.9E-02	1.4E-01	kg-1,4DCB-e (to ocean) / kg
Prochloraz	067747-09-5				1.4E-02			kg-1,4DCB-e (to ocean) / kg
Profenofos	041198-08-7				7.6E-02			kg-1,4DCB-e (to ocean) / kg
Prometryn	007287-19-6				3.9E-02			kg-1,4DCB-e (to ocean) / kg
Pronamide	023950-58-5				1.3E-01			kg-1,4DCB-e (to ocean) / kg
Propachlor	001918-16-7				1.6E-01			kg-1,4DCB-e (to ocean) / kg
Propamocarb	024579-73-5				1.6E-04			kg-1,4DCB-e (to ocean) / kg
Propane, 1,2-dibromo-3-chloro-	000096-12-8	4.4E-02	4.5E-02					kg-1,4DCB-e (to ocean) / kg
Propane, 1,2-dichloro-	000078-87-5	2.1E-02	2.1E-02			2.3E-02	1.0E-01	kg-1,4DCB-e (to ocean) / kg

		Impact Factors						
		Emission to Air		Emission to Soil		Emission to Water		
Substance	CAS	high pop / unspecified	low pop.	agricultural	industrial / unspecified	freshwater / unspecified	ocean	
Propanil	000709-98-8				4.9E-03			kg-1,4DCB-e (to ocean) / kg
Propaquizafop	111479-05-1				1.8E-03			kg-1,4DCB-e (to ocean) / kg
Propargite	002312-35-8				5.8E-03			kg-1,4DCB-e (to ocean) / kg
Propene, 1,3-dichloro-	000542-75-6	5.8E-05	7.8E-05		3.9E-05	6.2E-05	9.8E-03	kg-1,4DCB-e (to ocean) / kg
Propham	000122-42-9				1.4E-03			kg-1,4DCB-e (to ocean) / kg
Propiconazole	060207-90-1				3.3E-02			kg-1,4DCB-e (to ocean) / kg
Propionic acid	000079-09-4	2.3E-03	2.6E-03					kg-1,4DCB-e (to ocean) / kg
Propoxur	000114-26-1				1.6E-03			kg-1,4DCB-e (to ocean) / kg
Prosulfocarb	052888-80-9				1.5E-03			kg-1,4DCB-e (to ocean) / kg
Pyrazophos	013457-18-6				6.5E-02			kg-1,4DCB-e (to ocean) / kg
Pyrene	000129-00-0	1.0E-02	2.3E-02			4.8E-04	3.6E-01	kg-1,4DCB-e (to ocean) / kg
Pyridaben	096489-71-3				9.2E+00			kg-1,4DCB-e (to ocean) / kg
Pyridate	055512-33-9				1.3E-05			kg-1,4DCB-e (to ocean) / kg
Pyridine	000110-86-1	2.2E-03	2.7E-03			2.3E-04	4.7E-03	kg-1,4DCB-e (to ocean) / kg
Pyriproxyfen	095737-68-1				1.0E-01			kg-1,4DCB-e (to ocean) / kg
Quinmerac	090717-03-6				2.7E-04			kg-1,4DCB-e (to ocean) / kg
Quizalofop ethyl ester	076578-14-8				2.2E-03			kg-1,4DCB-e (to ocean) / kg
Resmethrin	010453-86-8				1.4E-02			kg-1,4DCB-e (to ocean) / kg
Rimsulfuron	122931-48-0				2.9E-03			kg-1,4DCB-e (to ocean) / kg
Rotenone	000083-79-4				1.4E-02			kg-1,4DCB-e (to ocean) / kg
Selenium	007782-49-2	5.0E+01	5.6E+01	1.9E+01	3.7E+01	8.9E+01	1.0E+02	kg-1,4DCB-e (to ocean) / kg
Sethoxydim	074051-80-2				2.1E-04			kg-1,4DCB-e (to ocean) / kg
Silver	007440-22-4	1.2E+03	1.7E+03	1.3E+01	2.5E+01			kg-1,4DCB-e (to ocean) / kg
Silver, ion	014701-21-4					3.2E+02	3.6E+03	kg-1,4DCB-e (to ocean) / kg
Simazine	000122-34-9				5.6E-02			kg-1,4DCB-e (to ocean) / kg
Sodium azide	026628-22-8	3.3E-02	4.0E-02			4.7E-03	1.1E-01	kg-1,4DCB-e (to ocean) / kg
Sodium dimethyldithiocarbamate	000128-04-1	3.9E-01	6.1E-01			3.8E-01	2.7E+00	kg-1,4DCB-e (to ocean) / kg
Starane	081406-37-3				2.8E-05			kg-1,4DCB-e (to ocean) / kg
Styrene	000100-42-5	1.7E-04	3.8E-04			5.9E-03	1.9E-01	kg-1,4DCB-e (to ocean) / kg
Sulprofos	035400-43-2				4.1E-04			kg-1,4DCB-e (to ocean) / kg
t-Butyl alcohol	000075-65-0					2.3E-03	3.5E-03	kg-1,4DCB-e (to ocean) / kg
Tebufenozide	112410-23-8				6.3E-03			kg-1,4DCB-e (to ocean) / kg
Tebuthiuron	034014-18-1				1.2E-03			kg-1,4DCB-e (to ocean) / kg
Terbacil	005902-51-2				5.9E-04			kg-1,4DCB-e (to ocean) / kg
Terbufos	013071-79-9				2.3E+00			kg-1,4DCB-e (to ocean) / kg
Terbuthylazin	005915-41-3				5.0E-02			kg-1,4DCB-e (to ocean) / kg
Terbutryn	000886-50-0				7.6E-02			kg-1,4DCB-e (to ocean) / kg
Thallium	007440-28-0	3.2E+01	4.5E+01	1.3E+00	2.5E+00	6.9E+01	9.5E+01	kg-1,4DCB-e (to ocean) / kg
Thiabendazole	000148-79-8				5.4E-03			kg-1,4DCB-e (to ocean) / kg
Thidiazuron	051707-55-2				7.7E-03			kg-1,4DCB-e (to ocean) / kg
Thiobencarb	028249-77-6				5.3E-02			kg-1,4DCB-e (to ocean) / kg
Thiodicarb	059669-26-0				7.0E-01			kg-1,4DCB-e (to ocean) / kg
Thiophanat-methyl	023564-05-8				2.6E-04			kg-1,4DCB-e (to ocean) / kg
Thiram	000137-26-8				8.0E-02			kg-1,4DCB-e (to ocean) / kg
Tin	007440-31-5	3.4E+00	4.9E+00	1.8E-03	2.6E-03			kg-1,4DCB-e (to ocean) / kg
Tin, ion	022537-50-4					6.8E-01	1.1E+01	kg-1,4DCB-e (to ocean) / kg
Tolclophos-methyl	057018-04-9				6.6E-03			kg-1,4DCB-e (to ocean) / kg
Toluene	000108-88-3	9.1E-05	1.0E-04			6.3E-04	2.2E-02	kg-1,4DCB-e (to ocean) / kg
Toluene, 2,4,6-trinitro-	000118-96-7	1.3E-04	1.9E-04			1.5E-07	4.1E-04	kg-1,4DCB-e (to ocean) / kg
Toluene, 2,4-dinitro-	000121-14-2	3.8E-03	4.9E-03			5.7E-05	8.7E-03	kg-1,4DCB-e (to ocean) / kg
Toluene, 2,6-dinitro-	000606-20-2	2.7E-04	3.8E-04			2.6E-06	7.2E-04	kg-1,4DCB-e (to ocean) / kg
Tralomethrin	066841-25-6				2.5E-03			kg-1,4DCB-e (to ocean) / kg
Triadimefon	043121-43-3				8.7E-03			kg-1,4DCB-e (to ocean) / kg
Triadimenol	055219-65-3				2.4E-03			kg-1,4DCB-e (to ocean) / kg
Tri-allate	002303-17-5				8.0E-01			kg-1,4DCB-e (to ocean) / kg
Triazofos	024017-47-8				1.1E+00			kg-1,4DCB-e (to ocean) / kg
Tribufos	000078-48-8					3.2E+00	5.6E+01	kg-1,4DCB-e (to ocean) / kg
Tributyltin compounds	(blank)					9.3E+02	2.1E+03	kg-1,4DCB-e (to ocean) / kg
Trichlorfon	000052-68-6				2.3E-04			kg-1,4DCB-e (to ocean) / kg
Triclopyr	055335-06-3				4.9E-03			kg-1,4DCB-e (to ocean) / kg
Triethylene glycol	000112-27-6					7.9E-07	1.9E-05	kg-1,4DCB-e (to ocean) / kg
Trifluralin	001582-09-8				1.0E-01			kg-1,4DCB-e (to ocean) / kg
Triforine	026644-46-2				5.3E-02			kg-1,4DCB-e (to ocean) / kg
Urea	(blank)				1.9E-06			kg-1,4DCB-e (to ocean) / kg
Vanadium	007440-62-2	7.2E+01	1.0E+02	1.9E+00	3.6E+00			kg-1,4DCB-e (to ocean) / kg
Vanadium, ion	022541-77-1					9.5E+01	2.2E+02	kg-1,4DCB-e (to ocean) / kg
Vinclozolin	050471-44-8				5.5E-03			kg-1,4DCB-e (to ocean) / kg
Vinyl acetate	000108-05-4	6.9E-04	1.1E-03					kg-1,4DCB-e (to ocean) / kg
Xylene	001330-20-7	1.3E-04	1.7E-04			1.8E-03	5.8E-02	kg-1,4DCB-e (to ocean) / kg
Zinc	007440-66-6	9.7E+00	1.4E+01	1.4E-02	7.5E-02			kg-1,4DCB-e (to ocean) / kg
Zinc, ion	023713-49-7					3.0E+00	3.3E+01	kg-1,4DCB-e (to ocean) / kg
Zineb	012122-67-7				2.9E-02			kg-1,4DCB-e (to ocean) / kg

Freshwater Ecotoxicity Potential

		Impact Factors						
		Air		Soil		Water		
Substance	CAS	low. pop.	high pop / unspecified	agricultural	industrial / unspecified	ocean	freshwater / unspecified	
1,4-Dioxane	000123-91-1	9.6E-05	1.3E-04			7.7E-06	8.9E-03	kg-1,4DCB-e (to freshwater) / kg
1-Butanol	000071-36-3					6.8E-07	7.8E-03	kg-1,4DCB-e (to freshwater) / kg
1-Octanol	000111-87-5	1.5E-03	1.2E-03			2.5E-05	2.8E-01	kg-1,4DCB-e (to freshwater) / kg
2,4,5-T	000093-76-5				2.0E-01			kg-1,4DCB-e (to freshwater) / kg
2,4-D	000094-75-7				2.9E-02			kg-1,4DCB-e (to freshwater) / kg
2-Benzothiazolethiol	000149-30-4	2.3E-01	1.0E+00			6.0E-05	1.4E+01	kg-1,4DCB-e (to freshwater) / kg
2-Butanol	000078-92-2					3.3E-07	3.2E-03	kg-1,4DCB-e (to freshwater) / kg
2-Butenal	004170-30-3	1.2E-03	1.1E-03			1.2E-05	3.0E-01	kg-1,4DCB-e (to freshwater) / kg
2-Ethoxyethyl acetate	000111-15-9	7.0E-04	1.1E-03			1.7E-06	7.4E-02	kg-1,4DCB-e (to freshwater) / kg
2-Propanol	000067-63-0					1.9E-07	1.4E-03	kg-1,4DCB-e (to freshwater) / kg
Abamectin	071751-41-2				2.0E+01			kg-1,4DCB-e (to freshwater) / kg
Acenaphthene	000083-32-9					2.8E-06	2.4E+00	kg-1,4DCB-e (to freshwater) / kg
Acephate	030560-19-1				1.4E-01			kg-1,4DCB-e (to freshwater) / kg
Acetaldehyde	000075-07-0	4.9E-04	3.8E-04					kg-1,4DCB-e (to freshwater) / kg
Acetaminophen	000103-90-2	1.2E-03	2.9E-03	4.7E-03			3.0E-02	kg-1,4DCB-e (to freshwater) / kg
Acetic acid	000064-19-7	2.6E-03	9.5E-03			3.4E-07	4.5E-02	kg-1,4DCB-e (to freshwater) / kg
Acetone	000067-64-1	1.8E-05	1.8E-05			5.8E-07	9.9E-04	kg-1,4DCB-e (to freshwater) / kg
Acetonitrile	000075-05-8	1.6E-04	1.7E-04			2.4E-05	7.6E-03	kg-1,4DCB-e (to freshwater) / kg
Aclonifen	074070-46-5				7.1E-01			kg-1,4DCB-e (to freshwater) / kg
Acrolein	000107-02-8	5.8E-01	4.9E-01					kg-1,4DCB-e (to freshwater) / kg
Acrylamide	000079-06-1	1.0E-03	3.7E-03			7.2E-10	4.3E-02	kg-1,4DCB-e (to freshwater) / kg
Acrylic acid	000079-10-7	1.7E-03	7.0E-03			5.1E-11	4.0E-02	kg-1,4DCB-e (to freshwater) / kg
Acrylonitrile	000107-13-1					2.9E-04	3.4E-01	kg-1,4DCB-e (to freshwater) / kg
Aldehydes, unspecified	(blank)	3.9E-03	1.2E-02					kg-1,4DCB-e (to freshwater) / kg
Aldicarb	000116-06-3				3.8E+01			kg-1,4DCB-e (to freshwater) / kg
Aldoxycarb	001646-88-4				1.5E+00			kg-1,4DCB-e (to freshwater) / kg
Allyl chloride	000107-05-1	1.1E-05	8.0E-06			7.5E-07	2.4E-01	kg-1,4DCB-e (to freshwater) / kg
Allylamine	000107-11-9	7.3E-04	4.9E-04			1.3E-05	2.9E-01	kg-1,4DCB-e (to freshwater) / kg
Alpha-cypermethrin	067375-30-8				1.1E+01			kg-1,4DCB-e (to freshwater) / kg
Ametryn	000834-12-8				9.5E+00			kg-1,4DCB-e (to freshwater) / kg
Amitraz	033089-61-1				4.9E-02			kg-1,4DCB-e (to freshwater) / kg
Aniline	000062-53-3	7.9E-03	4.0E-02			2.0E-08	6.2E-01	kg-1,4DCB-e (to freshwater) / kg
Aniline, 3,4-dichloro-	000095-76-1	1.1E-02	3.6E-02	5.0E-01			3.6E+00	kg-1,4DCB-e (to freshwater) / kg
Anthracene	000120-12-7	1.8E-02	1.4E-02		1.5E-02	2.3E-06	3.9E+00	kg-1,4DCB-e (to freshwater) / kg
Antimony	007440-36-0	8.0E-01	1.5E+00	1.6E+00	3.2E+00	1.5E-22	1.5E+01	kg-1,4DCB-e (to freshwater) / kg
Arsenic	007440-38-2	2.3E-01	2.0E-01	8.6E-02	1.4E-01			kg-1,4DCB-e (to freshwater) / kg
Arsenic, ion	017428-41-0					5.0E-23	1.6E+01	kg-1,4DCB-e (to freshwater) / kg
Atrazine	001912-24-9				2.8E+01			kg-1,4DCB-e (to freshwater) / kg
Azadirachtin	011141-17-6				1.7E+00			kg-1,4DCB-e (to freshwater) / kg
Azinphos-methyl	000086-50-0				7.9E+00			kg-1,4DCB-e (to freshwater) / kg
Barium	007440-39-3	1.8E-01	3.6E-01	3.9E-01	7.6E-01	3.2E-23	3.2E-23	kg-1,4DCB-e (to freshwater) / kg
Bendiocarb	022781-23-3				8.6E+00			kg-1,4DCB-e (to freshwater) / kg
Benomyl	017804-35-2				6.0E-02			kg-1,4DCB-e (to freshwater) / kg
Bentazone	025057-89-0				3.9E-02			kg-1,4DCB-e (to freshwater) / kg
Benzaldehyde	000100-52-7	1.7E-03	1.5E-03			3.3E-05	2.9E-01	kg-1,4DCB-e (to freshwater) / kg
Benzenamine, 4-methyl-	000106-49-0	8.8E-03	1.1E-02			2.4E-03	6.5E+00	kg-1,4DCB-e (to freshwater) / kg
Benzene	000071-43-2	3.3E-05	3.2E-05			6.2E-06	6.8E-02	kg-1,4DCB-e (to freshwater) / kg
Benzene, 1,2,4-trichloro-	000120-82-1	4.9E-03	4.9E-03			2.7E-03	3.5E+00	kg-1,4DCB-e (to freshwater) / kg
Benzene, 1,2-dichloro-	000095-50-1	1.1E-03	1.1E-03			6.2E-04	7.6E-01	kg-1,4DCB-e (to freshwater) / kg
Benzene, 1,3,5-trimethyl-	000108-67-8					9.6E-07	3.3E-01	kg-1,4DCB-e (to freshwater) / kg
Benzene, 1,3-dichloro-	000541-73-1	5.1E-04	5.0E-04			2.8E-04	5.5E-01	kg-1,4DCB-e (to freshwater) / kg
Benzene, 1,3-dinitro-	000099-65-0	8.9E-01	2.5E+00			6.2E-04	1.2E+01	kg-1,4DCB-e (to freshwater) / kg
Benzene, 1,4-dichloro-	000106-46-7	1.2E-03	1.2E-03			6.6E-04	1.0E+00	kg-1,4DCB-e (to freshwater) / kg
Benzene, 1,4-dinitro-	000100-25-4	1.5E-01	1.5E-01			3.8E-02	8.5E+00	kg-1,4DCB-e (to freshwater) / kg
Benzene, chloro-	000108-90-7					2.5E-04	7.2E-01	kg-1,4DCB-e (to freshwater) / kg
Benzene, ethyl-	000100-41-4	2.5E-05	2.2E-05			3.0E-06	2.2E-01	kg-1,4DCB-e (to freshwater) / kg
Benzene, hexachloro-	000118-74-1	1.4E-01	1.4E-01					kg-1,4DCB-e (to freshwater) / kg
Benzene, pentachloro-	000608-93-5	6.5E-02	6.5E-02					kg-1,4DCB-e (to freshwater) / kg
Benzo(a)pyrene	000050-32-8	3.9E-03	2.2E-03					kg-1,4DCB-e (to freshwater) / kg
Benzyl chloride	000100-44-7	3.1E-03	2.9E-03			5.6E-05	9.3E-01	kg-1,4DCB-e (to freshwater) / kg
Beryllium	007440-41-7	3.8E+01	8.1E+01	8.9E+01	1.8E+02	1.7E-20	4.4E+02	kg-1,4DCB-e (to freshwater) / kg
Bifenox	042576-02-3				1.3E-01			kg-1,4DCB-e (to freshwater) / kg
Bifenthrin	082657-04-3				3.2E+00			kg-1,4DCB-e (to freshwater) / kg
Bisphenol A	000080-05-7	7.0E-03	7.1E-02	9.0E-04			1.3E+00	kg-1,4DCB-e (to freshwater) / kg
Bitertanol	055179-31-2				1.1E-01			kg-1,4DCB-e (to freshwater) / kg
Botran	000099-30-9				1.3E+00			kg-1,4DCB-e (to freshwater) / kg
Bromacil	000314-40-9				9.9E-02			kg-1,4DCB-e (to freshwater) / kg
Bromine	007726-95-6	1.0E-01	1.0E-01	7.1E-01	3.6E+00	1.6E-02	3.4E+01	kg-1,4DCB-e (to freshwater) / kg
Bromoform	000075-25-2	2.4E-03	2.4E-03					kg-1,4DCB-e (to freshwater) / kg
Bromoxynil	001689-84-5				5.4E+00			kg-1,4DCB-e (to freshwater) / kg
Bromuconazole	116255-48-2				4.8E+00			kg-1,4DCB-e (to freshwater) / kg
Butadiene, hexachloro-	000087-68-3	5.8E-03	5.8E-03					kg-1,4DCB-e (to freshwater) / kg
Butylate	002008-41-5				5.8E-03			kg-1,4DCB-e (to freshwater) / kg
Cadmium	007440-43-9	2.0E-01	4.7E-01	1.5E-01	7.8E-01			kg-1,4DCB-e (to freshwater) / kg
Cadmium, ion	022537-48-0					1.8E-23	9.1E+00	kg-1,4DCB-e (to freshwater) / kg
Captan	000133-06-2				2.1E-02			kg-1,4DCB-e (to freshwater) / kg
Carbamic acid, butyl-, 3-iodo-2-prop	055406-53-6	3.1E-01	6.8E-01			2.4E-05	5.2E+01	kg-1,4DCB-e (to freshwater) / kg
Carbaryl	000063-25-2				4.5E-01			kg-1,4DCB-e (to freshwater) / kg
Carbetamide	016118-49-3				5.8E-02			kg-1,4DCB-e (to freshwater) / kg
Carbofuran	001563-66-2				1.5E+01			kg-1,4DCB-e (to freshwater) / kg
Carbon disulfide	000075-15-0	4.8E-05	4.6E-05					kg-1,4DCB-e (to freshwater) / kg

		Impact Factors						
		Air		Soil		Water		
Substance	CAS	low. pop.	high pop / unspecified	agricultural	industrial / unspecified	ocean	freshwater / unspecified	
Carboxin	005234-68-4				3.3E-01			kg-1,4DCB-e (to freshwater) / kg
Carboxylic acids, unspecified	(blank)					3.7E-11	3.4E-02	kg-1,4DCB-e (to freshwater) / kg
Chlorfenvinphos	000470-90-6				1.7E+01			kg-1,4DCB-e (to freshwater) / kg
Chloridazon	001698-60-8				2.4E-02			kg-1,4DCB-e (to freshwater) / kg
Chlorine	007782-50-5	1.2E-02	1.2E-02			2.4E-03	1.9E+01	kg-1,4DCB-e (to freshwater) / kg
Chlormequat chloride	000999-81-5				2.4E-02			kg-1,4DCB-e (to freshwater) / kg
Chloroform	000067-66-3	1.8E-04	1.8E-04			1.0E-04	1.5E-01	kg-1,4DCB-e (to freshwater) / kg
Chloropicrin	000076-06-2				1.4E+00			kg-1,4DCB-e (to freshwater) / kg
Chlorothalonil	001897-45-6				2.2E-01			kg-1,4DCB-e (to freshwater) / kg
Chlorotoluron	015545-48-9				1.1E+00			kg-1,4DCB-e (to freshwater) / kg
Chlorpropham	000101-21-3				9.1E-01			kg-1,4DCB-e (to freshwater) / kg
Chlorpyrifos	002921-88-2				9.8E+00			kg-1,4DCB-e (to freshwater) / kg
Chlorsulfuron	064902-72-3				1.5E+00			kg-1,4DCB-e (to freshwater) / kg
Chromium VI	018540-29-9	1.3E-02	1.0E-02	3.3E-03	4.5E-03	9.6E-25	9.0E-01	kg-1,4DCB-e (to freshwater) / kg
Clopyralid	001702-17-6				1.4E-01			kg-1,4DCB-e (to freshwater) / kg
Cloquintocet-mexyl	099607-70-2				3.2E-03			kg-1,4DCB-e (to freshwater) / kg
Cobalt	007440-48-4	2.8E+00	5.9E+00	6.4E+00	1.3E+01	6.5E-22	3.3E+01	kg-1,4DCB-e (to freshwater) / kg
Copper	007440-50-8	1.8E+00	4.4E+00	6.4E-01	2.1E+00			kg-1,4DCB-e (to freshwater) / kg
Cumene	000098-82-8	3.3E-05	2.9E-05			3.0E-06	3.8E-01	kg-1,4DCB-e (to freshwater) / kg
Cyanazine	021725-46-2				6.3E-01			kg-1,4DCB-e (to freshwater) / kg
Cyanide	000057-12-5	9.2E-02	9.3E-02			5.3E-03	6.1E+00	kg-1,4DCB-e (to freshwater) / kg
Cycloate	001134-23-2				4.2E-02			kg-1,4DCB-e (to freshwater) / kg
Cyclohexane	000110-82-7					1.5E-05	5.4E-02	kg-1,4DCB-e (to freshwater) / kg
Cyclohexanol	000108-93-0					4.0E-07	1.2E-02	kg-1,4DCB-e (to freshwater) / kg
Cyclohexylamine	000108-91-8	1.2E-03	1.7E-03			1.8E-05	3.7E-01	kg-1,4DCB-e (to freshwater) / kg
Cyclopentadiene, hexachloro-	000077-47-4	1.3E-06	1.2E-06					kg-1,4DCB-e (to freshwater) / kg
Cycloxydim	101205-02-1				3.9E-03			kg-1,4DCB-e (to freshwater) / kg
Cyfluthrin	068359-37-5				5.0E+00			kg-1,4DCB-e (to freshwater) / kg
Cymoxanil	057966-95-7				7.2E-03			kg-1,4DCB-e (to freshwater) / kg
Cypermethrin	052315-07-8				1.7E+03			kg-1,4DCB-e (to freshwater) / kg
Cyromazine	066215-27-8				2.8E+00			kg-1,4DCB-e (to freshwater) / kg
Daminozide	001596-84-5				9.6E-03			kg-1,4DCB-e (to freshwater) / kg
DDAC	007173-51-5				5.5E-02			kg-1,4DCB-e (to freshwater) / kg
Deltamethrin	052918-63-5				5.3E-01			kg-1,4DCB-e (to freshwater) / kg
Desmedipham	013684-56-5				1.0E-02			kg-1,4DCB-e (to freshwater) / kg
Desmetryn	001014-69-3				2.5E+00			kg-1,4DCB-e (to freshwater) / kg
Diazinon	000333-41-5				1.2E+01			kg-1,4DCB-e (to freshwater) / kg
Dibenzofuran	000132-64-9	1.5E-02	1.4E-02			2.0E-03	3.8E+00	kg-1,4DCB-e (to freshwater) / kg
Dicamba	001918-00-9				1.9E-01			kg-1,4DCB-e (to freshwater) / kg
Dichlobenil	001194-65-6				2.3E-01			kg-1,4DCB-e (to freshwater) / kg
Dichlorvos	000062-73-7				5.1E-02			kg-1,4DCB-e (to freshwater) / kg
Dicofol	000115-32-2				5.4E-02			kg-1,4DCB-e (to freshwater) / kg
Dicyclopentadiene	000077-73-6	6.0E-06	1.8E-06			1.0E-06	6.5E-01	kg-1,4DCB-e (to freshwater) / kg
Diethanolamine	000111-42-2	5.1E-04	2.6E-03			1.7E-11	3.7E-02	kg-1,4DCB-e (to freshwater) / kg
Difenoconazole	119446-68-3				6.7E-01			kg-1,4DCB-e (to freshwater) / kg
Difenzoquat	043222-48-6				1.5E-01			kg-1,4DCB-e (to freshwater) / kg
Diflubenzuron	035367-38-5				1.2E+01			kg-1,4DCB-e (to freshwater) / kg
Dimethipin	055290-64-7				2.6E-01			kg-1,4DCB-e (to freshwater) / kg
Dimethoate	000060-51-5				4.3E+00			kg-1,4DCB-e (to freshwater) / kg
Dimethylamine	000124-40-3	8.3E-05	5.4E-05			3.5E-07	3.5E-02	kg-1,4DCB-e (to freshwater) / kg
Dinoseb	000088-85-7				2.8E+01			kg-1,4DCB-e (to freshwater) / kg
Dinoterb	001420-07-1				1.4E+01			kg-1,4DCB-e (to freshwater) / kg
Diphenamid	000957-51-7				3.7E-02			kg-1,4DCB-e (to freshwater) / kg
Dipropylthiocarbamic acid S-ethyl e	000759-94-4	1.4E-03	9.0E-04		1.2E-02	1.1E-04	1.0E+00	kg-1,4DCB-e (to freshwater) / kg
Diquat dibromide	000085-00-7				8.6E-01			kg-1,4DCB-e (to freshwater) / kg
Disodium acid methane arsenate	000144-21-8				3.5E-02			kg-1,4DCB-e (to freshwater) / kg
Disulfoton	000298-04-4				5.3E-01			kg-1,4DCB-e (to freshwater) / kg
Dithianon	003347-22-6				5.7E+00			kg-1,4DCB-e (to freshwater) / kg
Diuron	000330-54-1				1.2E+01			kg-1,4DCB-e (to freshwater) / kg
DNOC	000534-52-1				1.1E+00			kg-1,4DCB-e (to freshwater) / kg
Dodine	002439-10-3				2.3E+00			kg-1,4DCB-e (to freshwater) / kg
EDTA	000060-00-4					2.0E-15	4.6E-02	kg-1,4DCB-e (to freshwater) / kg
Endosulfan	000115-29-7				7.5E-01			kg-1,4DCB-e (to freshwater) / kg
Endothall	000145-73-3				3.1E-02			kg-1,4DCB-e (to freshwater) / kg
Epichlorohydrin	000106-89-8	7.8E-03	8.0E-03					kg-1,4DCB-e (to freshwater) / kg
Epoxiconazole	106325-08-0				1.9E+00			kg-1,4DCB-e (to freshwater) / kg
Esfenvalerate	066230-04-4				6.0E+02			kg-1,4DCB-e (to freshwater) / kg
Ethane, 1,1,1-trichloro-, HCFC-140	000071-55-6	7.8E-05	7.8E-05			3.3E-05	1.2E-01	kg-1,4DCB-e (to freshwater) / kg
Ethane, 1,1,2,2-tetrachloro-	000079-34-5	3.8E-03	3.8E-03			1.0E-04	4.9E-01	kg-1,4DCB-e (to freshwater) / kg
Ethane, 1,1,2-trichloro-	000079-00-5	4.1E-04	4.1E-04					kg-1,4DCB-e (to freshwater) / kg
Ethane, 1,2-dibromo-	000106-93-4	2.0E-03	2.0E-03			9.4E-04	5.0E-01	kg-1,4DCB-e (to freshwater) / kg
Ethane, 1,2-dichloro-	000107-06-2		1.8E-04			1.4E-04	5.1E-02	kg-1,4DCB-e (to freshwater) / kg
Ethane, hexachloro-	000067-72-1					2.0E-03	3.1E+00	kg-1,4DCB-e (to freshwater) / kg
Ethane, pentachloro-	000076-01-7	6.4E-04	6.5E-04					kg-1,4DCB-e (to freshwater) / kg
Ethanol	000064-17-5	9.1E-06	1.1E-05					kg-1,4DCB-e (to freshwater) / kg
Ethanol, 2-butoxy-	000111-76-2					1.2E-07	8.1E-03	kg-1,4DCB-e (to freshwater) / kg
Ethene, tetrachloro-	000127-18-4	2.8E-04	2.8E-04			1.5E-04	1.1E+00	kg-1,4DCB-e (to freshwater) / kg
Ethephon	016672-87-0				2.3E-02			kg-1,4DCB-e (to freshwater) / kg
Ethion	000563-12-2				5.4E-02			kg-1,4DCB-e (to freshwater) / kg
Ethofumesate	026225-79-6				1.5E-01			kg-1,4DCB-e (to freshwater) / kg
Ethoprop	013194-48-4				3.7E+01			kg-1,4DCB-e (to freshwater) / kg
Ethylene diamine	000107-15-3	1.4E-03	7.1E-03			3.2E-09	7.2E-02	kg-1,4DCB-e (to freshwater) / kg

		Impact Factors						
		Air		Soil		Water		
Substance	CAS	low. pop.	high pop / unspecified	agricultural	industrial / unspecified	ocean	freshwater / unspecified	
Ethylene glycol	000107-21-1					6.1E-09	8.4E-04	kg-1,4DCB-e (to freshwater) / kg
Ethylene oxide	000075-21-8	6.7E-04	6.7E-04			6.9E-05	4.5E-02	kg-1,4DCB-e (to freshwater) / kg
Etridiazole	002593-15-9				6.4E-01			kg-1,4DCB-e (to freshwater) / kg
Fenamiphos	022224-92-6				2.1E+01			kg-1,4DCB-e (to freshwater) / kg
Fenarimol	060168-88-9				3.8E+00			kg-1,4DCB-e (to freshwater) / kg
Fenbuconazole	114369-43-6				2.1E+00			kg-1,4DCB-e (to freshwater) / kg
Fenbutatin oxide	013356-08-6				2.1E-07			kg-1,4DCB-e (to freshwater) / kg
Fenitrothion	000122-14-5				4.1E+00			kg-1,4DCB-e (to freshwater) / kg
Fenpiclonil	074738-17-3				1.2E+00			kg-1,4DCB-e (to freshwater) / kg
Fenpropathrin	039515-41-8				3.9E+00			kg-1,4DCB-e (to freshwater) / kg
Fenpropimorph	067306-03-0				5.4E-02			kg-1,4DCB-e (to freshwater) / kg
Fentin acetate	000900-95-8				4.7E+00			kg-1,4DCB-e (to freshwater) / kg
Fentin hydroxide	000076-87-9				5.3E+00			kg-1,4DCB-e (to freshwater) / kg
Fenvalerate	051630-58-1				1.1E+00			kg-1,4DCB-e (to freshwater) / kg
Ferbam	014484-64-1				1.4E+01			kg-1,4DCB-e (to freshwater) / kg
Fluazifop-P-butyl	079241-46-6				1.0E-01			kg-1,4DCB-e (to freshwater) / kg
Fluazinam	079622-59-6				7.3E+01			kg-1,4DCB-e (to freshwater) / kg
Fluometuron	002164-17-2				5.0E-01			kg-1,4DCB-e (to freshwater) / kg
Fluoranthene	000206-44-0	3.8E-01	2.7E-01			5.8E-04	1.2E+02	kg-1,4DCB-e (to freshwater) / kg
Fluorochloridone	061213-25-0				5.1E-01			kg-1,4DCB-e (to freshwater) / kg
Flutolanil	066332-96-5				6.6E-02			kg-1,4DCB-e (to freshwater) / kg
Folpet	000133-07-3				6.1E+00			kg-1,4DCB-e (to freshwater) / kg
Fomesafen	072178-02-0				2.4E-02			kg-1,4DCB-e (to freshwater) / kg
Fonofos	000944-22-9				2.2E+00			kg-1,4DCB-e (to freshwater) / kg
Formaldehyde	000050-00-0	5.2E-03	1.6E-02			3.0E-06	2.0E-01	kg-1,4DCB-e (to freshwater) / kg
Formic acid	000064-18-6					1.9E-11	2.6E-02	kg-1,4DCB-e (to freshwater) / kg
Fosetyl-aluminium	039148-24-8				8.5E-02			kg-1,4DCB-e (to freshwater) / kg
Fuberidazole	003878-19-1				7.7E-01			kg-1,4DCB-e (to freshwater) / kg
Glufosinate ammonium	077182-82-2				2.7E-01			kg-1,4DCB-e (to freshwater) / kg
Glyphosate	001071-83-6				8.8E-03			kg-1,4DCB-e (to freshwater) / kg
Heptane	000142-82-5	6.5E-09	5.6E-09					kg-1,4DCB-e (to freshwater) / kg
Heptenophos	023560-59-0				4.5E-01			kg-1,4DCB-e (to freshwater) / kg
Hexane	000110-54-3	9.3E-08	8.3E-08					kg-1,4DCB-e (to freshwater) / kg
Hexazinone	051235-04-2				1.9E+00			kg-1,4DCB-e (to freshwater) / kg
Hexythiazox	078587-05-0				1.2E-02			kg-1,4DCB-e (to freshwater) / kg
Hydrazine	000302-01-2					6.6E-04	1.8E+01	kg-1,4DCB-e (to freshwater) / kg
Hydrazine, methyl-	000060-34-4	9.6E-02	1.5E-01					kg-1,4DCB-e (to freshwater) / kg
Hydrocarbons, aliphatic, alkanes, c	(blank)	8.3E-06	1.2E-05					kg-1,4DCB-e (to freshwater) / kg
Hydrocarbons, aromatic	(blank)	3.2E-05	3.1E-05			2.8E-04	1.0E+01	kg-1,4DCB-e (to freshwater) / kg
Hydrocarbons, chlorinated	(blank)		3.8E-04					kg-1,4DCB-e (to freshwater) / kg
Hydroquinone	000123-31-9	3.9E-02	1.7E-01			2.5E-11	1.3E+00	kg-1,4DCB-e (to freshwater) / kg
Hymexazol	010004-44-1				5.2E-02			kg-1,4DCB-e (to freshwater) / kg
Imazaquin	081335-37-7				1.4E-02			kg-1,4DCB-e (to freshwater) / kg
Ioxynil	001689-83-4				9.8E-01			kg-1,4DCB-e (to freshwater) / kg
Iprodion	036734-19-7				6.3E-02			kg-1,4DCB-e (to freshwater) / kg
Isofenphos	025311-71-1				9.6E-01			kg-1,4DCB-e (to freshwater) / kg
Isoproturon	034123-59-6				9.0E+00			kg-1,4DCB-e (to freshwater) / kg
Lambda-cyhalothrin	091465-08-6				2.0E+00			kg-1,4DCB-e (to freshwater) / kg
Lead	007439-92-1	5.7E-03	4.8E-03	1.1E-03	1.3E-03	1.4E-25	4.1E-01	kg-1,4DCB-e (to freshwater) / kg
Lindane	000058-89-9				2.0E+01			kg-1,4DCB-e (to freshwater) / kg
Linuron	000330-55-2				1.1E+01			kg-1,4DCB-e (to freshwater) / kg
Malathion	000121-75-5				1.3E+00			kg-1,4DCB-e (to freshwater) / kg
Maleic anhydride	000108-31-6	5.6E-08	4.0E-08			1.2E-22	4.0E-06	kg-1,4DCB-e (to freshwater) / kg
Maleic hydrazide	000123-33-1				3.4E-02			kg-1,4DCB-e (to freshwater) / kg
Mancozeb	008018-01-7				1.4E-02			kg-1,4DCB-e (to freshwater) / kg
Maneb	012427-38-2				6.2E-02			kg-1,4DCB-e (to freshwater) / kg
Manganese	007439-96-5	6.1E-02	4.6E-02	1.1E-02	1.2E-02	1.4E-23	4.4E+00	kg-1,4DCB-e (to freshwater) / kg
MCPA	000094-74-6				3.6E-02			kg-1,4DCB-e (to freshwater) / kg
MCPB	000094-81-5				4.4E-02			kg-1,4DCB-e (to freshwater) / kg
m-Cresol	000108-39-4	4.2E-03	1.3E-02		5.0E-02	5.7E-06	9.1E-01	kg-1,4DCB-e (to freshwater) / kg
Mecoprop	000093-65-2				3.0E-02			kg-1,4DCB-e (to freshwater) / kg
Mepiquat chloride	024307-26-4				2.5E-02			kg-1,4DCB-e (to freshwater) / kg
Mercury	007439-97-6	2.5E+00	3.3E+00	5.1E+00	9.8E+00	5.4E-02	9.3E+01	kg-1,4DCB-e (to freshwater) / kg
Metalaxil	057837-19-1				3.5E-01			kg-1,4DCB-e (to freshwater) / kg
Metamitron	041394-05-2				9.8E-02			kg-1,4DCB-e (to freshwater) / kg
Metam-sodium	000137-42-8				1.0E+01			kg-1,4DCB-e (to freshwater) / kg
Metazachlor	067129-08-2				1.1E+00			kg-1,4DCB-e (to freshwater) / kg
Methabenzthiazuron	018691-97-9				1.5E+00			kg-1,4DCB-e (to freshwater) / kg
Methacrylic acid, methyl ester	000080-62-6	1.5E-05	1.0E-05			3.5E-06	1.9E-02	kg-1,4DCB-e (to freshwater) / kg
Methamidophos	010265-92-6				4.5E+00			kg-1,4DCB-e (to freshwater) / kg
Methane, bromo-, Halon 1001	000074-83-9	2.6E-03	2.6E-03					kg-1,4DCB-e (to freshwater) / kg
Methane, dichloro-, HCC-30	000075-09-2		3.8E-05			1.0E-05	2.4E-02	kg-1,4DCB-e (to freshwater) / kg
Methane, tetrachloro-, CFC-10	000056-23-5	4.3E-04	4.3E-04			3.4E-04	4.9E-01	kg-1,4DCB-e (to freshwater) / kg
Methanol	000067-56-1	4.1E-05	5.1E-05			3.1E-07	1.9E-03	kg-1,4DCB-e (to freshwater) / kg
Methidathion	000950-37-8				1.3E+00			kg-1,4DCB-e (to freshwater) / kg
Methiocarb	002032-65-7				9.4E+00			kg-1,4DCB-e (to freshwater) / kg
Methomyl	016752-77-5				2.8E+01			kg-1,4DCB-e (to freshwater) / kg
Methyl acrylate	000096-33-3	1.3E-03	1.1E-03			6.6E-05	4.1E-01	kg-1,4DCB-e (to freshwater) / kg
Methyl ethyl ketone	000078-93-3					8.6E-07	1.9E-03	kg-1,4DCB-e (to freshwater) / kg
Metiram	009006-42-2				3.9E+00			kg-1,4DCB-e (to freshwater) / kg
Metobromuron	003060-89-7				1.1E+00			kg-1,4DCB-e (to freshwater) / kg
Metolachlor	051218-45-2				9.4E+00			kg-1,4DCB-e (to freshwater) / kg

		Impact Factors						
		Air		Soil		Water		
Substance	CAS	low. pop.	high pop / unspecified	agricultural	industrial / unspecified	ocean	freshwater / unspecified	
Metribuzin	021087-64-9				1.4E-01			kg-1,4DCB-e (to freshwater) / kg
Metsulfuron-methyl	074223-64-6				1.3E+02			kg-1,4DCB-e (to freshwater) / kg
Mevinfos	007786-34-7				3.8E+00			kg-1,4DCB-e (to freshwater) / kg
Molinate	002212-67-1				2.3E-02			kg-1,4DCB-e (to freshwater) / kg
Molybdenum	007439-98-7	3.3E-02	3.7E-02	2.6E-02	4.7E-02	6.9E-24	1.8E+00	kg-1,4DCB-e (to freshwater) / kg
Monochloramine	(blank)	2.8E+00	4.6E+00			3.0E-13	3.7E+01	kg-1,4DCB-e (to freshwater) / kg
Monoethanolamine	000141-43-5	1.1E-03	5.1E-03					kg-1,4DCB-e (to freshwater) / kg
Monolinuron	001746-81-2				1.9E+00			kg-1,4DCB-e (to freshwater) / kg
Monosodium acid methanearsonate	002163-80-6				4.2E-02			kg-1,4DCB-e (to freshwater) / kg
m-Xylene	000108-38-3	1.5E-05	9.9E-06			3.8E-06	4.3E-01	kg-1,4DCB-e (to freshwater) / kg
Myclobutanil	088671-89-0				7.0E-01			kg-1,4DCB-e (to freshwater) / kg
Naled	000300-76-5				2.4E+00			kg-1,4DCB-e (to freshwater) / kg
Naphthalene	000091-20-3	8.7E-04	6.0E-04			5.4E-05	1.3E+00	kg-1,4DCB-e (to freshwater) / kg
Napropamide	015299-99-7				4.9E-04			kg-1,4DCB-e (to freshwater) / kg
Nickel	007440-02-0	1.8E+00	2.9E+00	7.5E-01	5.3E+00			kg-1,4DCB-e (to freshwater) / kg
Nickel, ion	014701-22-5					4.1E-22	9.8E+01	kg-1,4DCB-e (to freshwater) / kg
Nitrilotriacetic acid	000139-13-9	5.4E-04	2.7E-03			7.8E-15	2.7E-02	kg-1,4DCB-e (to freshwater) / kg
Nitrobenzene	000098-95-3	1.7E-02	1.8E-02			1.9E-03	8.5E-01	kg-1,4DCB-e (to freshwater) / kg
Nitroglycerin	000055-63-0	4.0E-02	1.1E-01			1.8E-06	1.7E+00	kg-1,4DCB-e (to freshwater) / kg
N-Nitrosodiethylamine	000055-18-5	1.6E-03	2.4E-03					kg-1,4DCB-e (to freshwater) / kg
N-Nitrosodimethylamine	000062-75-9	1.9E-06	8.1E-06	5.0E-05			2.8E-04	kg-1,4DCB-e (to freshwater) / kg
Norflurazon	027314-13-2				8.3E-01			kg-1,4DCB-e (to freshwater) / kg
o-Cresol	000095-48-7	1.4E-03	2.9E-03			1.5E-06	3.0E-01	kg-1,4DCB-e (to freshwater) / kg
Oryzalin	019044-88-3				1.1E+00			kg-1,4DCB-e (to freshwater) / kg
o-Toluidine	000095-53-4	2.2E-09	6.6E-10			1.0E-10	8.1E-02	kg-1,4DCB-e (to freshwater) / kg
Oxadixyl	077732-09-3				2.2E-02			kg-1,4DCB-e (to freshwater) / kg
Oxamyl	023135-22-0				9.5E-01			kg-1,4DCB-e (to freshwater) / kg
Oxazepam	000604-75-1	0.0E+00	0.0E+00	0.0E+00			0.0E+00	kg-1,4DCB-e (to freshwater) / kg
Oxydemeton-methyl	000301-12-2				1.8E+00			kg-1,4DCB-e (to freshwater) / kg
Oxydiazon	019666-30-9				1.2E-01			kg-1,4DCB-e (to freshwater) / kg
Oxyfluorfen	042874-03-3				2.9E-01			kg-1,4DCB-e (to freshwater) / kg
o-Xylene	000095-47-6	3.6E-05	2.8E-05			9.2E-06	4.6E-01	kg-1,4DCB-e (to freshwater) / kg
Paclobutrazol	076738-62-0				1.2E-01			kg-1,4DCB-e (to freshwater) / kg
PAH, polycyclic aromatic hydrocarb	130498-29-2	2.1E-02	1.5E-02			5.3E-05	1.7E+00	kg-1,4DCB-e (to freshwater) / kg
Parathion	000056-38-2				2.0E+00			kg-1,4DCB-e (to freshwater) / kg
Parathion, methyl	000298-00-0				7.5E-01			kg-1,4DCB-e (to freshwater) / kg
p-Cresol	000106-44-5	2.3E-04	4.0E-04			1.3E-08	5.4E-02	kg-1,4DCB-e (to freshwater) / kg
Pendimethalin	040487-42-1				7.8E-01			kg-1,4DCB-e (to freshwater) / kg
Permethrin	052645-53-1	1.1E+00	1.4E+01	5.2E-01			4.0E+02	kg-1,4DCB-e (to freshwater) / kg
Phenanthrene	000085-01-8	2.1E-02	1.7E-02			2.0E-05	4.6E+00	kg-1,4DCB-e (to freshwater) / kg
Phenmedipham	013684-63-4				6.8E-04			kg-1,4DCB-e (to freshwater) / kg
Phenol	000108-95-2	6.5E-04	2.1E-03			6.1E-08	5.6E-02	kg-1,4DCB-e (to freshwater) / kg
Phenol, 2,4,5-trichloro-	000095-95-4	3.2E-02	3.9E-02			2.2E-06	2.0E+00	kg-1,4DCB-e (to freshwater) / kg
Phenol, 2,4,6-trichloro-	000088-06-2	2.5E-02	7.1E-02			2.2E-08	9.7E-01	kg-1,4DCB-e (to freshwater) / kg
Phenol, 2,4-dichloro-	000120-83-2	6.7E-04	8.9E-04			7.9E-09	5.0E-02	kg-1,4DCB-e (to freshwater) / kg
Phenol, 2,4-dimethyl-	000105-67-9	2.4E-03	5.0E-03			4.1E-06	8.7E-01	kg-1,4DCB-e (to freshwater) / kg
Phenol, 2,4-dinitro-	000051-28-5	4.7E-01	1.8E+00			6.8E-08	5.9E+00	kg-1,4DCB-e (to freshwater) / kg
Phenol, 2-nitro-	000088-75-5	2.6E-02	2.9E-02			9.4E-04	1.5E+00	kg-1,4DCB-e (to freshwater) / kg
Phenol, 4-nitro-	000100-02-7	1.1E-05	1.0E-05			1.1E-07	2.4E-01	kg-1,4DCB-e (to freshwater) / kg
Phenol, pentachloro-	000087-86-5	4.8E-02	4.9E-02					kg-1,4DCB-e (to freshwater) / kg
Phenytoin	000057-41-0	0.0E+00	0.0E+00	0.0E+00			0.0E+00	kg-1,4DCB-e (to freshwater) / kg
Phorate	000298-02-2				1.4E+00			kg-1,4DCB-e (to freshwater) / kg
Phosmet	000732-11-6				1.6E+00			kg-1,4DCB-e (to freshwater) / kg
Phosphorus	007723-14-0	1.5E-01	1.5E-01	1.1E+00	3.5E+00	1.1E-02	1.1E+02	kg-1,4DCB-e (to freshwater) / kg
Phthalate, butyl-benzyl-	000085-68-7					2.3E-05	3.6E+00	kg-1,4DCB-e (to freshwater) / kg
Phthalate, dibutyl-	000084-74-2					7.0E-05	1.2E+01	kg-1,4DCB-e (to freshwater) / kg
Phthalate, dimethyl-	000131-11-3					3.6E-07	1.2E-01	kg-1,4DCB-e (to freshwater) / kg
Phthalate, dioctyl-	000117-81-7					6.6E-05	3.0E-01	kg-1,4DCB-e (to freshwater) / kg
Picloram	001918-02-1				2.7E-01			kg-1,4DCB-e (to freshwater) / kg
Pirimicarb	023103-98-2				1.3E-01			kg-1,4DCB-e (to freshwater) / kg
Pirimiphos methyl	029232-93-7				1.6E+00			kg-1,4DCB-e (to freshwater) / kg
p-Nitroaniline	000100-01-6	8.6E-02	3.6E-01			3.9E-07	1.9E+00	kg-1,4DCB-e (to freshwater) / kg
Prochloraz	067747-09-5				6.7E-01			kg-1,4DCB-e (to freshwater) / kg
Profenofos	041198-08-7				4.8E+00			kg-1,4DCB-e (to freshwater) / kg
Prometryn	007287-19-6				1.8E+00			kg-1,4DCB-e (to freshwater) / kg
Pronamide	023950-58-5				1.8E-01			kg-1,4DCB-e (to freshwater) / kg
Propachlor	001918-16-7				4.1E+00			kg-1,4DCB-e (to freshwater) / kg
Propamocarb	024579-73-5				1.5E-02			kg-1,4DCB-e (to freshwater) / kg
Propane, 1,2-dibromo-3-chloro-	000096-12-8	4.0E-03	4.0E-03					kg-1,4DCB-e (to freshwater) / kg
Propane, 1,2-dichloro-	000078-87-5	7.7E-05	7.7E-05			6.2E-05	6.2E-02	kg-1,4DCB-e (to freshwater) / kg
Propanil	000709-98-8				2.5E-01			kg-1,4DCB-e (to freshwater) / kg
Propaquizafop	111479-05-1				3.1E-01			kg-1,4DCB-e (to freshwater) / kg
Propargite	002312-35-8				2.8E-01			kg-1,4DCB-e (to freshwater) / kg
Propene, 1,3-dichloro-	000542-75-6	8.6E-05	6.6E-05		3.6E-04	2.3E-07	3.8E-01	kg-1,4DCB-e (to freshwater) / kg
Propham	000122-42-9				1.1E-02			kg-1,4DCB-e (to freshwater) / kg
Propiconazole	060207-90-1				1.9E+00			kg-1,4DCB-e (to freshwater) / kg
Propoxur	000114-26-1				1.6E+00			kg-1,4DCB-e (to freshwater) / kg
Prosulfocarb	052888-80-9				1.0E-01			kg-1,4DCB-e (to freshwater) / kg
Pyrazophos	013457-18-6				2.2E+00			kg-1,4DCB-e (to freshwater) / kg
Pyrene	000129-00-0	3.3E-02	2.0E-02			2.3E-06	1.7E+01	kg-1,4DCB-e (to freshwater) / kg
Pyridaben	096489-71-3				1.2E+00			kg-1,4DCB-e (to freshwater) / kg
Pyridate	055512-33-9				1.2E-03			kg-1,4DCB-e (to freshwater) / kg

		Impact Factors						
		Air		Soil		Water		
Substance	CAS	low. pop.	high pop / unspecified	agricultural	industrial / unspecified	ocean	freshwater / unspecified	
Pyridine	000110-86-1	3.2E-03	9.5E-03			5.6E-08	6.9E-02	kg-1,4DCB-e (to freshwater) / kg
Pyriproxyfen	095737-68-1				1.4E-01			kg-1,4DCB-e (to freshwater) / kg
Quinmerac	090717-03-6				2.6E-02			kg-1,4DCB-e (to freshwater) / kg
Quizalofop ethyl ester	076578-14-8				1.9E-01			kg-1,4DCB-e (to freshwater) / kg
Resmethrin	010453-86-8				8.7E-01			kg-1,4DCB-e (to freshwater) / kg
Rimsulfuron	122931-48-0				2.8E-01			kg-1,4DCB-e (to freshwater) / kg
Rotenone	000083-79-4				1.3E+00			kg-1,4DCB-e (to freshwater) / kg
Selenium	007782-49-2	1.1E+01	2.4E+01	2.6E+01	5.2E+01	2.4E-21	8.5E+01	kg-1,4DCB-e (to freshwater) / kg
Sethoxydim	074051-80-2				2.0E-02			kg-1,4DCB-e (to freshwater) / kg
Silver	007440-22-4	1.6E+01	2.8E+01	2.8E+01	5.6E+01			kg-1,4DCB-e (to freshwater) / kg
Silver, ion	014701-21-4					1.5E-21	4.0E+02	kg-1,4DCB-e (to freshwater) / kg
Simazine	000122-34-9				2.3E+00			kg-1,4DCB-e (to freshwater) / kg
Sodium azide	026628-22-8	1.1E-01	3.1E-01			5.8E-26	1.7E+00	kg-1,4DCB-e (to freshwater) / kg
Sodium dimethyldithiocarbamate	000128-04-1	1.7E+00	7.1E+00			4.6E-12	3.7E+01	kg-1,4DCB-e (to freshwater) / kg
Starane	081406-37-3				6.7E-03			kg-1,4DCB-e (to freshwater) / kg
Styrene	000100-42-5	2.2E-05	1.0E-05			6.9E-06	3.6E-01	kg-1,4DCB-e (to freshwater) / kg
Sulprofos	035400-43-2				3.4E-03			kg-1,4DCB-e (to freshwater) / kg
t-Butyl alcohol	000075-65-0					3.3E-05	7.3E-03	kg-1,4DCB-e (to freshwater) / kg
Tebufenozide	112410-23-8				2.9E-01			kg-1,4DCB-e (to freshwater) / kg
Tebuthiuron	034014-18-1				1.2E-01			kg-1,4DCB-e (to freshwater) / kg
Terbacil	005902-51-2				5.7E-02			kg-1,4DCB-e (to freshwater) / kg
Terbufos	013071-79-9				2.6E+01			kg-1,4DCB-e (to freshwater) / kg
Terbuthylazin	005915-41-3				1.4E+00			kg-1,4DCB-e (to freshwater) / kg
Terbutryn	000886-50-0				3.3E+00			kg-1,4DCB-e (to freshwater) / kg
Thallium	007440-28-0	1.7E+00	2.4E+00	2.2E+00	4.1E+00	2.6E-22	6.7E+01	kg-1,4DCB-e (to freshwater) / kg
Thiabendazole	000148-79-8				5.2E-01			kg-1,4DCB-e (to freshwater) / kg
Thidiazuron	051707-55-2				7.4E-01			kg-1,4DCB-e (to freshwater) / kg
Thiobencarb	028249-77-6				7.6E-01			kg-1,4DCB-e (to freshwater) / kg
Thiodicarb	059669-26-0				6.1E+00			kg-1,4DCB-e (to freshwater) / kg
Thiophanat-methyl	023564-05-8				9.2E-02			kg-1,4DCB-e (to freshwater) / kg
Thiram	000137-26-8				1.4E+01			kg-1,4DCB-e (to freshwater) / kg
Tin	007440-31-5	1.4E-02	1.1E-02	4.4E-03	6.7E-03			kg-1,4DCB-e (to freshwater) / kg
Tin, ion	022537-50-4					6.3E-25	9.4E-01	kg-1,4DCB-e (to freshwater) / kg
Tolclophos-methyl	057018-04-9				1.5E-02			kg-1,4DCB-e (to freshwater) / kg
Toluene	000108-88-3	1.3E-05	1.2E-05			1.4E-06	1.1E-01	kg-1,4DCB-e (to freshwater) / kg
Toluene, 2,4,6-trinitro-	000118-96-7	1.6E-03	5.8E-03			1.7E-11	1.9E-02	kg-1,4DCB-e (to freshwater) / kg
Toluene, 2,4-dinitro-	000121-14-2	2.8E-02	8.8E-02			1.8E-07	4.0E-01	kg-1,4DCB-e (to freshwater) / kg
Toluene, 2,6-dinitro-	000606-20-2	2.6E-03	9.0E-03			3.9E-09	3.3E-02	kg-1,4DCB-e (to freshwater) / kg
Tralomethrin	066841-25-6				8.9E-02			kg-1,4DCB-e (to freshwater) / kg
Triadimefon	043121-43-3				5.0E-01			kg-1,4DCB-e (to freshwater) / kg
Triadimenol	055219-65-3				2.3E-01			kg-1,4DCB-e (to freshwater) / kg
Tri-allate	002303-17-5				4.9E-01			kg-1,4DCB-e (to freshwater) / kg
Triazofos	024017-47-8				2.6E+01			kg-1,4DCB-e (to freshwater) / kg
Tribufos	000078-48-8					8.0E-03	4.8E+01	kg-1,4DCB-e (to freshwater) / kg
Tributyltin compounds	(blank)					3.3E-01	8.4E+03	kg-1,4DCB-e (to freshwater) / kg
Trichlorfon	000052-68-6				6.4E-01			kg-1,4DCB-e (to freshwater) / kg
Triclopyr	055335-06-3				4.5E-01			kg-1,4DCB-e (to freshwater) / kg
Triethylene glycol	000112-27-6					2.0E-12	2.8E-04	kg-1,4DCB-e (to freshwater) / kg
Trifluralin	001582-09-8				6.1E-02			kg-1,4DCB-e (to freshwater) / kg
Triforine	026644-46-2				8.5E-01			kg-1,4DCB-e (to freshwater) / kg
Urea	(blank)				6.7E-04			kg-1,4DCB-e (to freshwater) / kg
Vanadium	007440-62-2	2.4E+00	3.6E+00	3.2E+00	6.2E+00			kg-1,4DCB-e (to freshwater) / kg
Vanadium, ion	022541-77-1					5.9E-22	9.6E+01	kg-1,4DCB-e (to freshwater) / kg
Vinclozolin	050471-44-8				2.5E-01			kg-1,4DCB-e (to freshwater) / kg
Vinyl acetate	000108-05-4	1.2E-04	7.7E-05					kg-1,4DCB-e (to freshwater) / kg
Xylene	001330-20-7	1.1E-05	8.7E-06			2.9E-06	1.4E-01	kg-1,4DCB-e (to freshwater) / kg
Zinc	007440-66-6	1.3E-01	2.2E-01	4.9E-02	2.7E-01			kg-1,4DCB-e (to freshwater) / kg
Zinc, ion	023713-49-7					1.6E-23	7.5E+00	kg-1,4DCB-e (to freshwater) / kg
Zineb	012122-67-7				6.9E-01			kg-1,4DCB-e (to freshwater) / kg

Terrestrial Ecotoxicity Potential

		Impact Factors						
		Air		Soil		Water		
Substance	CAS	high pop / unspecified	low. pop.	agricultural	industrial / unspecified	freshwater / unspecified	ocean	
1,4-Dioxane	000123-91-1	2.1E-04	1.9E-04			1.1E-04	1.6E-05	kg-1,4DCB-e (to soil) / kg
1-Butanol	000071-36-3					1.9E-05	1.0E-06	kg-1,4DCB-e (to soil) / kg
1-Octanol	000111-87-5	3.0E-04	2.2E-04			5.9E-05	3.7E-06	kg-1,4DCB-e (to soil) / kg
2,4,5-T	000093-76-5				6.6E-01			kg-1,4DCB-e (to soil) / kg
2,4-D	000094-75-7				6.7E-01			kg-1,4DCB-e (to soil) / kg
2-Benzothiazolethiol	000149-30-4	4.8E-01	4.1E-01			2.1E-03	1.1E-04	kg-1,4DCB-e (to soil) / kg
2-Butanol	000078-92-2					7.5E-06	4.2E-07	kg-1,4DCB-e (to soil) / kg
2-Butenal	004170-30-3	3.3E-03	2.6E-03			4.6E-04	2.6E-05	kg-1,4DCB-e (to soil) / kg
2-Ethoxyethyl acetate	000111-15-9	3.9E-03	3.4E-03			2.1E-04	8.5E-06	kg-1,4DCB-e (to soil) / kg
2-Propanol	000067-63-0					2.3E-06	1.3E-07	kg-1,4DCB-e (to soil) / kg
Abamectin	071751-41-2				2.1E+01			kg-1,4DCB-e (to soil) / kg
Acenaphthene	000083-32-9					5.7E-05	1.1E-06	kg-1,4DCB-e (to soil) / kg
Acephate	030560-19-1				2.0E-01			kg-1,4DCB-e (to soil) / kg
Acetaldehyde	000075-07-0	5.6E-04	4.3E-04					kg-1,4DCB-e (to soil) / kg
Acetaminophen	000103-90-2	0.0E+00		0.0E+00		0.0E+00		kg-1,4DCB-e (to soil) / kg
Acetic acid	000064-19-7	5.4E-02	4.7E-02			1.3E-04	6.2E-06	kg-1,4DCB-e (to soil) / kg
Acetone	000067-64-1	3.0E-05	2.6E-05			1.1E-05	8.5E-07	kg-1,4DCB-e (to soil) / kg
Acetonitrile	000075-05-8	3.7E-04	3.2E-04			2.5E-04	4.8E-05	kg-1,4DCB-e (to soil) / kg
Aclonifen	074070-46-5				1.1E+00			kg-1,4DCB-e (to soil) / kg
Acrolein	000107-02-8	1.1E+00	8.9E-01					kg-1,4DCB-e (to soil) / kg
Acrylamide	000079-06-1	4.1E-03	2.9E-03			4.4E-08	2.0E-09	kg-1,4DCB-e (to soil) / kg
Acrylic acid	000079-10-7	1.9E-02	1.6E-02			1.0E-07	4.8E-10	kg-1,4DCB-e (to soil) / kg
Acrylonitrile	000107-13-1					2.5E-03	3.6E-04	kg-1,4DCB-e (to soil) / kg
Aldehydes, unspecified	(blank)	3.7E-02	2.9E-02					kg-1,4DCB-e (to soil) / kg
Aldicarb	000116-06-3				2.4E+02			kg-1,4DCB-e (to soil) / kg
Aldoxycarb	001646-88-4				3.5E+01			kg-1,4DCB-e (to soil) / kg
Allyl chloride	000107-05-1	1.2E-05	8.9E-06			6.8E-06	6.1E-07	kg-1,4DCB-e (to soil) / kg
Allylamine	000107-11-9	1.8E-03	1.3E-03			3.8E-04	2.4E-05	kg-1,4DCB-e (to soil) / kg
Alpha-cypermethrin	067375-30-8				3.9E+01			kg-1,4DCB-e (to soil) / kg
Ametryn	000834-12-8				2.0E+01			kg-1,4DCB-e (to soil) / kg
Amitraz	033089-61-1				1.4E-01			kg-1,4DCB-e (to soil) / kg
Aniline	000062-53-3	3.2E-02	3.3E-02			1.7E-05	8.5E-08	kg-1,4DCB-e (to soil) / kg
Aniline, 3,4-dichloro-	000095-76-1	9.4E+02		1.3E+04		5.3E-01		kg-1,4DCB-e (to soil) / kg
Anthracene	000120-12-7	2.1E-01	1.6E-01		6.4E+00	1.3E-03	2.0E-05	kg-1,4DCB-e (to soil) / kg
Antimony	007440-36-0	2.7E+00	2.0E+00	3.8E+00	4.2E+00	1.5E-21	9.0E-22	kg-1,4DCB-e (to soil) / kg
Arsenic	007440-38-2	1.4E-01	1.1E-01	2.1E-01	2.3E-01			kg-1,4DCB-e (to soil) / kg
Arsenic, ion	017428-41-0					5.0E-23	5.0E-23	kg-1,4DCB-e (to soil) / kg
Atrazine	001912-24-9				3.5E+01			kg-1,4DCB-e (to soil) / kg
Azadirachtin	011141-17-6				1.6E+01			kg-1,4DCB-e (to soil) / kg
Azinphos-methyl	000086-50-0				4.6E+01			kg-1,4DCB-e (to soil) / kg
Barium	007440-39-3	4.4E-01	3.3E-01	6.2E-01	6.9E-01	3.4E-22	1.5E-22	kg-1,4DCB-e (to soil) / kg
Bendiocarb	022781-23-3				5.6E+01			kg-1,4DCB-e (to soil) / kg
Benomyl	017804-35-2				1.2E-01			kg-1,4DCB-e (to soil) / kg
Bentazone	025057-89-0				4.6E-01			kg-1,4DCB-e (to soil) / kg
Benzaldehyde	000100-52-7	1.8E-03	1.4E-03			4.2E-04	2.7E-05	kg-1,4DCB-e (to soil) / kg
Benzenamine, 4-methyl-	000106-49-0	2.3E-02	1.4E-02			1.1E-02	4.7E-03	kg-1,4DCB-e (to soil) / kg
Benzene	000071-43-2	9.5E-05	9.3E-05			7.7E-05	1.8E-05	kg-1,4DCB-e (to soil) / kg
Benzene, 1,2,4-trichloro-	000120-82-1	7.0E-03	6.9E-03			6.6E-03	3.9E-03	kg-1,4DCB-e (to soil) / kg
Benzene, 1,2-dichloro-	000095-50-1	5.1E-03	5.0E-03			4.8E-03	2.9E-03	kg-1,4DCB-e (to soil) / kg
Benzene, 1,3,5-trimethyl-	000108-67-8					2.2E-06	4.7E-07	kg-1,4DCB-e (to soil) / kg
Benzene, 1,3-dichloro-	000541-73-1	1.8E-03	1.8E-03			1.7E-03	1.0E-03	kg-1,4DCB-e (to soil) / kg
Benzene, 1,3-dinitro-	000099-65-0	8.1E+00	6.7E+00			1.9E-01	4.7E-03	kg-1,4DCB-e (to soil) / kg
Benzene, 1,4-dichloro-	000106-46-7	5.4E-03	5.3E-03			5.1E-03	3.1E-03	kg-1,4DCB-e (to soil) / kg
Benzene, 1,4-dinitro-	000100-25-4	1.4E-01	1.3E-01			1.1E-01	3.3E-02	kg-1,4DCB-e (to soil) / kg
Benzene, chloro-	000108-90-7					1.1E-03	6.2E-04	kg-1,4DCB-e (to soil) / kg
Benzene, ethyl-	000100-41-4	2.1E-05	1.8E-05			1.4E-05	2.2E-06	kg-1,4DCB-e (to soil) / kg
Benzene, hexachloro-	000118-74-1	1.1E+00	1.1E+00					kg-1,4DCB-e (to soil) / kg
Benzene, pentachloro-	000608-93-5	1.6E-01	1.6E-01					kg-1,4DCB-e (to soil) / kg
Benzo(a)pyrene	000050-32-8	1.9E-01	1.0E-01					kg-1,4DCB-e (to soil) / kg
Benzyl chloride	000100-44-7	1.5E-03	1.4E-03			6.9E-04	2.5E-05	kg-1,4DCB-e (to soil) / kg
Beryllium	007440-41-7	9.1E+01	6.7E+01	1.3E+02	1.4E+02	2.0E-19	7.7E-20	kg-1,4DCB-e (to soil) / kg
Bifenox	042576-02-3				1.6E-01			kg-1,4DCB-e (to soil) / kg
Bifenthrin	082657-04-3				4.0E+01			kg-1,4DCB-e (to soil) / kg
Bisphenol A	000080-05-7	0.0E+00		0.0E+00		0.0E+00		kg-1,4DCB-e (to soil) / kg
Bitertanol	055179-31-2				2.0E-01			kg-1,4DCB-e (to soil) / kg
Botran	000099-30-9				3.0E+00			kg-1,4DCB-e (to soil) / kg
Bromacil	000314-40-9				4.8E-01			kg-1,4DCB-e (to soil) / kg
Bromine	007726-95-6	7.5E-01	7.4E-01	6.8E+01	6.5E+01	5.9E-01	1.2E-01	kg-1,4DCB-e (to soil) / kg
Bromoform	000075-25-2	7.6E-03	7.5E-03					kg-1,4DCB-e (to soil) / kg
Bromoxynil	001689-84-5				3.7E+00			kg-1,4DCB-e (to soil) / kg
Bromuconazole	116255-48-2				8.6E+00			kg-1,4DCB-e (to soil) / kg
Butadiene, hexachloro-	000087-68-3	4.7E-02	4.7E-02					kg-1,4DCB-e (to soil) / kg
Butylate	002008-41-5				3.6E-02			kg-1,4DCB-e (to soil) / kg

		Impact Factors						
		Air		Soil		Water		
Substance	CAS	high pop / unspecified	low. pop.	agricultural	industrial / unspecified	freshwater / unspecified	ocean	
Cadmium	007440-43-9	1.1E+01	5.1E+00	5.5E+00	1.8E+01			kg-1,4DCB-e (to soil) / kg
Cadmium, ion	022537-48-0					1.9E-22	5.2E-22	kg-1,4DCB-e (to soil) / kg
Captan	000133-06-2				1.8E-01			kg-1,4DCB-e (to soil) / kg
Carbamic acid, butyl-, 3-iodo-2-propynyl ester	055406-53-6	5.8E-01	3.7E-01			5.7E-03	2.9E-05	kg-1,4DCB-e (to soil) / kg
Carbaryl	000063-25-2				2.2E+00			kg-1,4DCB-e (to soil) / kg
Carbetamide	016118-49-3				6.2E-01			kg-1,4DCB-e (to soil) / kg
Carbofuran	001563-66-2				5.0E+01			kg-1,4DCB-e (to soil) / kg
Carbon disulfide	000075-15-0	1.1E-04	1.1E-04					kg-1,4DCB-e (to soil) / kg
Carboxin	005234-68-4				1.6E+00			kg-1,4DCB-e (to soil) / kg
Chlorfenvinphos	000470-90-6				2.7E+01			kg-1,4DCB-e (to soil) / kg
Chloridazon	001698-60-8				4.8E-01			kg-1,4DCB-e (to soil) / kg
Chlorine	007782-50-5	4.4E-01	4.4E-01			3.7E-01	8.6E-02	kg-1,4DCB-e (to soil) / kg
Chlormequat chloride	000999-81-5				1.5E-02			kg-1,4DCB-e (to soil) / kg
Chloroform	000067-66-3	1.5E-03	1.5E-03			1.4E-03	8.8E-04	kg-1,4DCB-e (to soil) / kg
Chloropicrin	000076-06-2				1.4E+02			kg-1,4DCB-e (to soil) / kg
Chlorothalonil	001897-45-6				3.0E+00			kg-1,4DCB-e (to soil) / kg
Chlorotoluron	015545-48-9				1.3E+00			kg-1,4DCB-e (to soil) / kg
Chlorpropham	000101-21-3				2.1E+00			kg-1,4DCB-e (to soil) / kg
Chlorpyrifos	002921-88-2				1.8E+01			kg-1,4DCB-e (to soil) / kg
Chlorsulfuron	064902-72-3				7.9E+00			kg-1,4DCB-e (to soil) / kg
Chromium VI	018540-29-9	6.9E-02	5.1E-02	9.8E-02	1.1E-01	1.1E-24	4.1E-24	kg-1,4DCB-e (to soil) / kg
Clopyralid	001702-17-6				1.9E+00			kg-1,4DCB-e (to soil) / kg
Cloquintocet-mexyl	099607-70-2				9.2E-03			kg-1,4DCB-e (to soil) / kg
Cobalt	007440-48-4	1.1E+01	8.1E+00	1.6E+01	1.7E+01	7.6E-21	4.7E-21	kg-1,4DCB-e (to soil) / kg
Copper	007440-50-8	3.3E+01	5.2E+00	6.0E+00	1.7E+01			kg-1,4DCB-e (to soil) / kg
Cumene	000098-82-8	2.4E-05	2.2E-05			1.5E-05	1.9E-06	kg-1,4DCB-e (to soil) / kg
Cyanazine	021725-46-2				1.1E+00			kg-1,4DCB-e (to soil) / kg
Cyanide	000057-12-5	2.1E-01	1.9E-01			1.1E-01	1.1E-02	kg-1,4DCB-e (to soil) / kg
Cycloate	001134-23-2				9.5E-02			kg-1,4DCB-e (to soil) / kg
Cyclohexane	000110-82-7					1.6E-05	1.0E-05	kg-1,4DCB-e (to soil) / kg
Cyclohexanol	000108-93-0					1.8E-05	9.3E-07	kg-1,4DCB-e (to soil) / kg
Cyclohexylamine	000108-91-8	2.3E-03	2.0E-03			4.8E-04	3.1E-05	kg-1,4DCB-e (to soil) / kg
Cyclopentadiene, hexachloro-	000077-47-4	9.6E-05	9.3E-05					kg-1,4DCB-e (to soil) / kg
Cycloxydim	101205-02-1				7.0E-03			kg-1,4DCB-e (to soil) / kg
Cyfluthrin	068359-37-5				1.6E+01			kg-1,4DCB-e (to soil) / kg
Cymoxanil	057966-95-7				1.3E-02			kg-1,4DCB-e (to soil) / kg
Cypermethrin	052315-07-8				1.1E+04			kg-1,4DCB-e (to soil) / kg
Cyromazine	066215-27-8				9.9E+00			kg-1,4DCB-e (to soil) / kg
Daminozide	001596-84-5				3.4E-01			kg-1,4DCB-e (to soil) / kg
DDAC	007173-51-5				1.6E-01			kg-1,4DCB-e (to soil) / kg
Deltamethrin	052918-63-5				1.0E+00			kg-1,4DCB-e (to soil) / kg
Desmedipham	013684-56-5				6.4E-02			kg-1,4DCB-e (to soil) / kg
Desmetryn	001014-69-3				2.3E+00			kg-1,4DCB-e (to soil) / kg
Diazinon	000333-41-5				1.7E+01			kg-1,4DCB-e (to soil) / kg
Dibenzofuran	000132-64-9	1.9E-03	1.7E-03			1.3E-03	2.3E-04	kg-1,4DCB-e (to soil) / kg
Dicamba	001918-00-9				2.4E-01			kg-1,4DCB-e (to soil) / kg
Dichlobenil	001194-65-6				9.6E-01			kg-1,4DCB-e (to soil) / kg
Dichlorvos	000062-73-7				3.6E-01			kg-1,4DCB-e (to soil) / kg
Dicofol	000115-32-2				2.0E-01			kg-1,4DCB-e (to soil) / kg
Dicyclopentadiene	000077-73-6	5.4E-06	3.1E-06			2.5E-06	5.2E-07	kg-1,4DCB-e (to soil) / kg
Diethanolamine	000111-42-2	4.5E-03	4.2E-03			3.3E-09	1.4E-10	kg-1,4DCB-e (to soil) / kg
Difenoconazole	119446-68-3				1.0E+00			kg-1,4DCB-e (to soil) / kg
Difenzoquat	043222-48-6				3.3E+00			kg-1,4DCB-e (to soil) / kg
Diflubenzuron	035367-38-5				2.1E+01			kg-1,4DCB-e (to soil) / kg
Dimethipin	055290-64-7				5.9E+00			kg-1,4DCB-e (to soil) / kg
Dimethoate	000060-51-5				1.1E+01			kg-1,4DCB-e (to soil) / kg
Dimethylamine	000124-40-3	9.0E-04	6.7E-04			5.8E-05	2.9E-06	kg-1,4DCB-e (to soil) / kg
Dinoseb	000088-85-7				5.3E+01			kg-1,4DCB-e (to soil) / kg
Dinoterb	001420-07-1				4.8E+00			kg-1,4DCB-e (to soil) / kg
Diphenamid	000957-51-7				9.3E-02			kg-1,4DCB-e (to soil) / kg
Dipropylthiocarbamic acid S-ethyl ester	000759-94-4	5.2E-04	3.7E-04		3.4E-01	2.4E-04	2.9E-05	kg-1,4DCB-e (to soil) / kg
Diquat dibromide	000085-00-7				2.0E+01			kg-1,4DCB-e (to soil) / kg
Disodium acid methane arsenate	000144-21-8				8.4E-01			kg-1,4DCB-e (to soil) / kg
Disulfoton	000298-04-4				7.9E-01			kg-1,4DCB-e (to soil) / kg
Dithianon	003347-22-6				1.3E+01			kg-1,4DCB-e (to soil) / kg
Diuron	000330-54-1				2.9E+01			kg-1,4DCB-e (to soil) / kg
DNOC	000534-52-1				2.7E+00			kg-1,4DCB-e (to soil) / kg
Dodine	002439-10-3				2.2E+01			kg-1,4DCB-e (to soil) / kg
EDTA	000060-00-4					1.0E-12	4.7E-14	kg-1,4DCB-e (to soil) / kg
Endosulfan	000115-29-7				1.3E+00			kg-1,4DCB-e (to soil) / kg
Endothall	000145-73-3				3.3E-01			kg-1,4DCB-e (to soil) / kg
Epichlorohydrin	000106-89-8	9.3E-03	8.1E-03					kg-1,4DCB-e (to soil) / kg
Epoxiconazole	106325-08-0				3.4E+00			kg-1,4DCB-e (to soil) / kg
Esfenvalerate	066230-04-4				6.1E+02			kg-1,4DCB-e (to soil) / kg

		Impact Factors						
		Air		Soil		Water		
Substance	CAS	high pop / unspecified	low. pop.	agricultural	industrial / unspecified	freshwater / unspecified	ocean	
Ethane, 1,1,1-trichloro-, HCFC-140	000071-55-6	1.8E-03	1.8E-03			1.7E-03	7.6E-04	kg-1,4DCB-e (to soil) / kg
Ethane, 1,1,2,2-tetrachloro-	000079-34-5	5.8E-03	5.4E-03			4.8E-03	1.4E-04	kg-1,4DCB-e (to soil) / kg
Ethane, 1,1,2-trichloro-	000079-00-5	2.3E-03	2.3E-03					kg-1,4DCB-e (to soil) / kg
Ethane, 1,2-dibromo-	000106-93-4	6.0E-03	5.9E-03			5.6E-03	2.9E-03	kg-1,4DCB-e (to soil) / kg
Ethane, 1,2-dichloro-	000107-06-2	9.9E-04	9.8E-04			9.7E-04	8.1E-04	kg-1,4DCB-e (to soil) / kg
Ethane, hexachloro-	000067-72-1					3.6E-02	2.1E-02	kg-1,4DCB-e (to soil) / kg
Ethane, pentachloro-	000076-01-7	1.5E-03	1.5E-03					kg-1,4DCB-e (to soil) / kg
Ethanol	000064-17-5	3.7E-05	2.8E-05					kg-1,4DCB-e (to soil) / kg
Ethanol, 2-butoxy-	000111-76-2					1.5E-05	7.3E-07	kg-1,4DCB-e (to soil) / kg
Ethene, tetrachloro-	000127-18-4	2.6E-03	2.6E-03			2.5E-03	1.5E-03	kg-1,4DCB-e (to soil) / kg
Ethene, trichloro-	000079-01-6	5.5E-05	5.2E-05			5.0E-05	2.4E-05	kg-1,4DCB-e (to soil) / kg
Ethephon	016672-87-0				5.2E-01			kg-1,4DCB-e (to soil) / kg
Ethion	000563-12-2				1.6E-01			kg-1,4DCB-e (to soil) / kg
Ethofumesate	026225-79-6				4.3E-01			kg-1,4DCB-e (to soil) / kg
Ethylene diamine	000107-15-3	2.8E-02	2.9E-02			1.4E-06	6.6E-08	kg-1,4DCB-e (to soil) / kg
Ethylene glycol	000107-21-1					9.2E-07	4.5E-08	kg-1,4DCB-e (to soil) / kg
Ethylene oxide	000075-21-8	9.9E-04	9.0E-04			7.6E-04	9.4E-05	kg-1,4DCB-e (to soil) / kg
Etridiazole	002593-15-9				1.1E+00			kg-1,4DCB-e (to soil) / kg
Fenamiphos	022224-92-6				4.4E+01			kg-1,4DCB-e (to soil) / kg
Fenarimol	060168-88-9				4.1E+00			kg-1,4DCB-e (to soil) / kg
Fenbutatin oxide	013356-08-6				1.8E-06			kg-1,4DCB-e (to soil) / kg
Fenitrothion	000122-14-5				6.8E+00			kg-1,4DCB-e (to soil) / kg
Fenpiclonil	074738-17-3				1.9E+00			kg-1,4DCB-e (to soil) / kg
Fenpropathrin	039515-41-8				9.2E+00			kg-1,4DCB-e (to soil) / kg
Fenpropimorph	067306-03-0				1.1E-01			kg-1,4DCB-e (to soil) / kg
Fentin acetate	000900-95-8				2.5E+01			kg-1,4DCB-e (to soil) / kg
Fentin hydroxide	000076-87-9				2.8E+01			kg-1,4DCB-e (to soil) / kg
Fenvalerate	051630-58-1				4.1E+00			kg-1,4DCB-e (to soil) / kg
Ferbam	014484-64-1				2.4E+02			kg-1,4DCB-e (to soil) / kg
Fluazifop-P-butyl	079241-46-6				1.8E-01			kg-1,4DCB-e (to soil) / kg
Fluazinam	079622-59-6				1.1E+02			kg-1,4DCB-e (to soil) / kg
Fluometuron	002164-17-2				1.7E+00			kg-1,4DCB-e (to soil) / kg
Fluoranthene	000206-44-0	3.2E-01	2.1E-01			1.8E-02	3.2E-04	kg-1,4DCB-e (to soil) / kg
Fluorochloridone	061213-25-0				8.6E-01			kg-1,4DCB-e (to soil) / kg
Flutolanil	066332-96-5				1.2E-01			kg-1,4DCB-e (to soil) / kg
Folpet	000133-07-3				1.9E+01			kg-1,4DCB-e (to soil) / kg
Fomesafen	072178-02-0				4.9E-02			kg-1,4DCB-e (to soil) / kg
Fonofos	000944-22-9				5.3E+00			kg-1,4DCB-e (to soil) / kg
Formaldehyde	000050-00-0	5.1E-02	4.0E-02			4.9E-04	2.3E-05	kg-1,4DCB-e (to soil) / kg
Formic acid	000064-18-6					2.3E-08	1.1E-10	kg-1,4DCB-e (to soil) / kg
Fosetyl-aluminium	039148-24-8				2.0E+00			kg-1,4DCB-e (to soil) / kg
Fuberidazole	003878-19-1				2.3E+00			kg-1,4DCB-e (to soil) / kg
Glufosinate ammonium	077182-82-2				6.4E+00			kg-1,4DCB-e (to soil) / kg
Glyphosate	001071-83-6				1.1E-02			kg-1,4DCB-e (to soil) / kg
Heptane	000142-82-5	9.5E-09	8.3E-09					kg-1,4DCB-e (to soil) / kg
Heptenophos	023560-59-0				1.0E+00			kg-1,4DCB-e (to soil) / kg
Hexane	000110-54-3	1.5E-07	1.3E-07					kg-1,4DCB-e (to soil) / kg
Hexazinone	051235-04-2				1.2E+01			kg-1,4DCB-e (to soil) / kg
Hexythiazox	078587-05-0				3.1E-02			kg-1,4DCB-e (to soil) / kg
Hydrazine	000302-01-2					1.2E-01	5.5E-03	kg-1,4DCB-e (to soil) / kg
Hydrazine, methyl-	000060-34-4	2.2E-01	1.9E-01					kg-1,4DCB-e (to soil) / kg
Hydrocarbons, aliphatic, alkanes, cyclic	(blank)	1.6E-05	1.4E-05					kg-1,4DCB-e (to soil) / kg
Hydrocarbons, aromatic	(blank)	9.2E-05	9.0E-05			2.8E-03	5.9E-04	kg-1,4DCB-e (to soil) / kg
Hydrocarbons, chlorinated	(blank)	2.1E-03	2.1E-03					kg-1,4DCB-e (to soil) / kg
Hydroquinone	000123-31-9	5.9E+00	5.1E+00			2.2E-07	3.4E-09	kg-1,4DCB-e (to soil) / kg
Hymexazol	010004-44-1				1.1E+00			kg-1,4DCB-e (to soil) / kg
Imazaquin	081335-37-7				8.8E-02			kg-1,4DCB-e (to soil) / kg
Ioxynil	001689-83-4				1.6E+00			kg-1,4DCB-e (to soil) / kg
Iprodion	036734-19-7				2.3E-01			kg-1,4DCB-e (to soil) / kg
Isofenphos	025311-71-1				1.7E+00			kg-1,4DCB-e (to soil) / kg
Isoproturon	034123-59-6				2.6E+01			kg-1,4DCB-e (to soil) / kg
Lambda-cyhalothrin	091465-08-6				1.2E+01			kg-1,4DCB-e (to soil) / kg
Lead	007439-92-1	7.1E-02	6.0E-03	5.8E-03	2.0E-02	3.6E-26	1.2E-25	kg-1,4DCB-e (to soil) / kg
Lindane	000058-89-9				2.7E+01			kg-1,4DCB-e (to soil) / kg
Linuron	000330-55-2				1.9E+01			kg-1,4DCB-e (to soil) / kg
Malathion	000121-75-5				8.3E-01			kg-1,4DCB-e (to soil) / kg
Maleic anhydride	000108-31-6	2.0E-07	1.2E-07			1.8E-20	2.7E-22	kg-1,4DCB-e (to soil) / kg
Maleic hydrazide	000123-33-1				8.0E-01			kg-1,4DCB-e (to soil) / kg
Mancozeb	008018-01-7				4.7E-02			kg-1,4DCB-e (to soil) / kg
Maneb	012427-38-2				1.7E+00			kg-1,4DCB-e (to soil) / kg
Manganese	007439-96-5	3.7E-05	2.8E-05	5.3E-05	5.9E-05	1.0E-26	1.3E-26	kg-1,4DCB-e (to soil) / kg
MCPA	000094-74-6				1.4E-01			kg-1,4DCB-e (to soil) / kg
MCPB	000094-81-5				8.5E-02			kg-1,4DCB-e (to soil) / kg
m-Cresol	000108-39-4	9.7E-03	8.0E-03		3.5E-01	3.4E-04	1.1E-05	kg-1,4DCB-e (to soil) / kg
Mecoprop	000093-65-2				2.8E-01			kg-1,4DCB-e (to soil) / kg
Mepiquat chloride	024307-26-4				5.9E-01			kg-1,4DCB-e (to soil) / kg
Mercury	007439-97-6	1.0E+02	7.9E+01	2.7E+02	3.0E+02	6.4E-01	2.1E+00	kg-1,4DCB-e (to soil) / kg

		Impact Factors						
		Air		Soil		Water		
Substance	CAS	high pop / unspecified	low. pop.	agricultural	industrial / unspecified	freshwater / unspecified	ocean	
Metalaxil	057837-19-1				2.3E+00			kg-1,4DCB-e (to soil) / kg
Metamitron	041394-05-2				2.2E-01			kg-1,4DCB-e (to soil) / kg
Metam-sodium	000137-42-8				2.5E+02			kg-1,4DCB-e (to soil) / kg
Metazachlor	067129-08-2				1.4E+00			kg-1,4DCB-e (to soil) / kg
Methabenzthiazuron	018691-97-9				2.3E+00			kg-1,4DCB-e (to soil) / kg
Methacrylic acid, methyl ester	000080-62-6	1.5E-05	1.1E-05			9.3E-06	2.5E-06	kg-1,4DCB-e (to soil) / kg
Methamidophos	010265-92-6				1.8E+01			kg-1,4DCB-e (to soil) / kg
Methane, bromo-, Halon 1001	000074-83-9	2.9E-02	2.9E-02					kg-1,4DCB-e (to soil) / kg
Methane, dichloro-, HCC-30	000075-09-2	2.0E-04	2.0E-04			1.7E-04	5.1E-05	kg-1,4DCB-e (to soil) / kg
Methane, tetrachloro-, CFC-10	000056-23-5	1.4E-02	1.4E-02			1.4E-02	1.1E-02	kg-1,4DCB-e (to soil) / kg
Methanol	000067-56-1	1.4E-04	1.1E-04			1.5E-05	8.1E-07	kg-1,4DCB-e (to soil) / kg
Methidathion	000950-37-8				8.0E+00			kg-1,4DCB-e (to soil) / kg
Methiocarb	002032-65-7				2.6E+01			kg-1,4DCB-e (to soil) / kg
Methomyl	016752-77-5				6.0E+01			kg-1,4DCB-e (to soil) / kg
Methoxychlor	000072-43-5				4.3E+00			kg-1,4DCB-e (to soil) / kg
Methyl acrylate	000096-33-3	1.1E-03	8.7E-04			4.7E-04	4.6E-05	kg-1,4DCB-e (to soil) / kg
Methyl ethyl ketone	000078-93-3					1.5E-05	1.1E-06	kg-1,4DCB-e (to soil) / kg
Metiram	009006-42-2				6.8E+01			kg-1,4DCB-e (to soil) / kg
Metobromuron	003060-89-7				3.9E+00			kg-1,4DCB-e (to soil) / kg
Metolachlor	051218-45-2				1.5E+01			kg-1,4DCB-e (to soil) / kg
Metribuzin	021087-64-9				5.2E+00			kg-1,4DCB-e (to soil) / kg
Metsulfuron-methyl	074223-64-6				5.4E+02			kg-1,4DCB-e (to soil) / kg
Molinate	002212-67-1				8.7E-02			kg-1,4DCB-e (to soil) / kg
Molybdenum	007439-98-7	2.3E-02	1.7E-02	3.3E-02	3.7E-02	2.2E-23	8.8E-24	kg-1,4DCB-e (to soil) / kg
Monochloramine	(blank)	6.5E+01	6.5E+01			1.0E-10	7.1E-12	kg-1,4DCB-e (to soil) / kg
Monoethanolamine	000141-43-5	1.4E-02	1.3E-02					kg-1,4DCB-e (to soil) / kg
Monolinuron	001746-81-2				4.7E+00			kg-1,4DCB-e (to soil) / kg
Monosodium acid methanearsonate	002163-80-6				1.0E+00			kg-1,4DCB-e (to soil) / kg
Myclobutanil	088671-89-0				1.7E+00			kg-1,4DCB-e (to soil) / kg
Naled	000300-76-5				1.1E+02			kg-1,4DCB-e (to soil) / kg
Naphthalene	000091-20-3	3.8E-04	2.8E-04			1.7E-04	1.8E-05	kg-1,4DCB-e (to soil) / kg
Napropamide	015299-99-7				8.6E-01			kg-1,4DCB-e (to soil) / kg
Nickel	007440-02-0	5.1E+00	2.5E+00	1.9E+00	1.1E+01			kg-1,4DCB-e (to soil) / kg
Nickel, ion	014701-22-5					1.3E-21	8.4E-22	kg-1,4DCB-e (to soil) / kg
Nitrilotriacetic acid	000139-13-9	1.1E-02	1.2E-02			3.8E-12	1.7E-13	kg-1,4DCB-e (to soil) / kg
Nitrobenzene	000098-95-3	1.3E-02	1.1E-02			8.4E-03	1.3E-03	kg-1,4DCB-e (to soil) / kg
Nitroglycerin	000055-63-0	3.5E-02	2.4E-02			2.7E-05	1.1E-06	kg-1,4DCB-e (to soil) / kg
N-Nitrosodiethylamine	000055-18-5	6.7E-03	6.0E-03					kg-1,4DCB-e (to soil) / kg
N-Nitrosodimethylamine	000062-75-9	0.0E+00		0.0E+00		0.0E+00		kg-1,4DCB-e (to soil) / kg
Norflurazon	027314-13-2				3.1E+00			kg-1,4DCB-e (to soil) / kg
o-Cresol	000095-48-7	1.7E-03	1.1E-03			3.0E-05	1.2E-06	kg-1,4DCB-e (to soil) / kg
Oryzalin	019044-88-3				1.7E+00			kg-1,4DCB-e (to soil) / kg
o-Toluidine	000095-53-4	5.1E-09	2.8E-09			1.6E-09	1.3E-10	kg-1,4DCB-e (to soil) / kg
Oxadixyl	077732-09-3				3.7E-01			kg-1,4DCB-e (to soil) / kg
Oxamyl	023135-22-0				7.5E+00			kg-1,4DCB-e (to soil) / kg
Oxazepam	000604-75-1	0.0E+00		0.0E+00		0.0E+00		kg-1,4DCB-e (to soil) / kg
Oxydemeton-methyl	000301-12-2				3.2E+00			kg-1,4DCB-e (to soil) / kg
Oxydiazon	019666-30-9				2.0E-01			kg-1,4DCB-e (to soil) / kg
Oxyfluorfen	042874-03-3				4.6E-01			kg-1,4DCB-e (to soil) / kg
o-Xylene	000095-47-6	2.9E-05	2.3E-05			2.0E-05	5.8E-06	kg-1,4DCB-e (to soil) / kg
Paclobutrazol	076738-62-0				2.1E-01			kg-1,4DCB-e (to soil) / kg
PAH, polycyclic aromatic hydrocarbons	130498-29-2	1.1E-01	6.7E-02			2.4E-04	1.8E-05	kg-1,4DCB-e (to soil) / kg
Parathion	000056-38-2				3.0E+00			kg-1,4DCB-e (to soil) / kg
Parathion, methyl	000298-00-0				1.7E+00			kg-1,4DCB-e (to soil) / kg
p-Cresol	000106-44-5	8.9E-04	5.5E-04			7.2E-07	3.1E-08	kg-1,4DCB-e (to soil) / kg
Pendimethalin	040487-42-1				1.1E+00			kg-1,4DCB-e (to soil) / kg
Permethrin	052645-53-1	3.2E+00		6.5E+01		2.4E-04		kg-1,4DCB-e (to soil) / kg
Phenanthrene	000085-01-8	1.9E-02	1.4E-02			8.5E-04	1.4E-05	kg-1,4DCB-e (to soil) / kg
Phenmedipham	013684-63-4				4.4E-03			kg-1,4DCB-e (to soil) / kg
Phenol	000108-95-2	7.4E-03	5.6E-03			1.7E-05	5.3E-07	kg-1,4DCB-e (to soil) / kg
Phenol, 2,4,5-trichloro-	000095-95-4	3.5E-01	3.0E-01			4.5E-03	2.1E-05	kg-1,4DCB-e (to soil) / kg
Phenol, 2,4,6-trichloro-	000088-06-2	3.3E-01	2.3E-01			4.5E-05	2.0E-07	kg-1,4DCB-e (to soil) / kg
Phenol, 2,4-dichloro-	000120-83-2	4.1E-02	3.3E-02			6.3E-05	3.9E-07	kg-1,4DCB-e (to soil) / kg
Phenol, 2,4-dimethyl-	000105-67-9	5.8E-03	4.4E-03			1.8E-04	7.3E-06	kg-1,4DCB-e (to soil) / kg
Phenol, 2,4-dinitro-	000051-28-5	3.2E+00	3.2E+00			2.1E-04	4.7E-07	kg-1,4DCB-e (to soil) / kg
Phenol, 2-nitro-	000088-75-5	3.5E-02	3.1E-02			1.3E-02	1.1E-03	kg-1,4DCB-e (to soil) / kg
Phenol, 4-nitro-	000100-02-7	3.8E-05	3.6E-05			1.2E-05	3.4E-07	kg-1,4DCB-e (to soil) / kg
Phenol, pentachloro-	000087-86-5	1.6E-01	1.0E-01					kg-1,4DCB-e (to soil) / kg
Phenytoin	000057-41-0	0.0E+00		0.0E+00		0.0E+00		kg-1,4DCB-e (to soil) / kg
Phorate	000298-02-2				4.8E+00			kg-1,4DCB-e (to soil) / kg
Phosmet	000732-11-6				6.4E+00			kg-1,4DCB-e (to soil) / kg
Phosphorus	007723-14-0	2.9E+00	2.9E+00	1.3E+02	1.3E+02	1.8E+00	2.1E-01	kg-1,4DCB-e (to soil) / kg
Phthalate, butyl-benzyl-	000085-68-7					7.9E-05	3.8E-06	kg-1,4DCB-e (to soil) / kg
Phthalate, dibutyl-	000084-74-2					5.1E-04	2.5E-05	kg-1,4DCB-e (to soil) / kg
Phthalate, dimethyl-	000131-11-3					7.2E-06	3.4E-07	kg-1,4DCB-e (to soil) / kg
Phthalate, dioctyl-	000117-81-7					5.6E-06	1.7E-06	kg-1,4DCB-e (to soil) / kg
Picloram	001918-02-1				2.9E+00			kg-1,4DCB-e (to soil) / kg

		Impact Factors						
		Air		Soil		Water		
Substance	CAS	high pop / unspecified	low. pop.	agricultural	industrial / unspecified	freshwater / unspecified	ocean	
Pirimicarb	023103-98-2				6.3E-01			kg-1,4DCB-e (to soil) / kg
Pirimiphos methyl	029232-93-7				2.8E+00			kg-1,4DCB-e (to soil) / kg
p-Nitroaniline	000100-01-6	5.4E-01	5.4E-01			4.9E-05	2.5E-06	kg-1,4DCB-e (to soil) / kg
Prochloraz	067747-09-5				1.0E+00			kg-1,4DCB-e (to soil) / kg
Profenofos	041198-08-7				8.9E+00			kg-1,4DCB-e (to soil) / kg
Prometryn	007287-19-6				3.0E+00			kg-1,4DCB-e (to soil) / kg
Pronamide	023950-58-5				4.7E-01			kg-1,4DCB-e (to soil) / kg
Propachlor	001918-16-7				1.0E+01			kg-1,4DCB-e (to soil) / kg
Propamocarb	024579-73-5				2.1E-01			kg-1,4DCB-e (to soil) / kg
Propane, 1,2-dibromo-3-chloro-	000096-12-8	1.9E-03	1.8E-03					kg-1,4DCB-e (to soil) / kg
Propane, 1,2-dichloro-	000078-87-5	4.7E-04	4.6E-04			4.6E-04	4.1E-04	kg-1,4DCB-e (to soil) / kg
Propanil	000709-98-8				5.6E-01			kg-1,4DCB-e (to soil) / kg
Propaquizafop	111479-05-1				5.7E-01			kg-1,4DCB-e (to soil) / kg
Propargite	002312-35-8				5.7E-01			kg-1,4DCB-e (to soil) / kg
Propene, 1,3-dichloro-	000542-75-6	1.6E-04	1.3E-04		1.2E-01	1.9E-05	3.5E-07	kg-1,4DCB-e (to soil) / kg
Propham	000122-42-9				7.3E-02			kg-1,4DCB-e (to soil) / kg
Propiconazole	060207-90-1				2.0E+00			kg-1,4DCB-e (to soil) / kg
Propionic acid	000079-09-4	4.1E-02	3.5E-02					kg-1,4DCB-e (to soil) / kg
Propoxur	000114-26-1				3.8E+01			kg-1,4DCB-e (to soil) / kg
Prosulfocarb	052888-80-9				1.9E-01			kg-1,4DCB-e (to soil) / kg
Pyrazophos	013457-18-6				3.2E+00			kg-1,4DCB-e (to soil) / kg
Pyrene	000129-00-0	1.0E+00	7.0E-01			3.2E-03	4.8E-05	kg-1,4DCB-e (to soil) / kg
Pyridaben	096489-71-3				4.3E+00			kg-1,4DCB-e (to soil) / kg
Pyridate	055512-33-9				3.3E-03			kg-1,4DCB-e (to soil) / kg
Pyridine	000110-86-1	2.9E-02	2.5E-02			9.1E-05	4.4E-07	kg-1,4DCB-e (to soil) / kg
Pyriproxyfen	095737-68-1				3.4E-01			kg-1,4DCB-e (to soil) / kg
Quinmerac	090717-03-6				6.6E-02			kg-1,4DCB-e (to soil) / kg
Quizalofop ethyl ester	076578-14-8				3.3E-01			kg-1,4DCB-e (to soil) / kg
Resmethrin	010453-86-8				3.3E+00			kg-1,4DCB-e (to soil) / kg
Rotenone	000083-79-4				2.2E+00			kg-1,4DCB-e (to soil) / kg
Selenium	007782-49-2	2.6E+01	1.9E+01	3.6E+01	4.0E+01	2.9E-20	1.1E-20	kg-1,4DCB-e (to soil) / kg
Sethoxydim	074051-80-2				3.5E-02			kg-1,4DCB-e (to soil) / kg
Silver	007440-22-4	6.5E+02	4.9E+02	9.3E+02	1.0E+03			kg-1,4DCB-e (to soil) / kg
Silver, ion	014701-21-4					2.5E-20	7.4E-20	kg-1,4DCB-e (to soil) / kg
Simazine	000122-34-9				1.0E+01			kg-1,4DCB-e (to soil) / kg
Sodium azide	026628-22-8	2.3E+00	2.3E+00			2.6E-23	1.2E-24	kg-1,4DCB-e (to soil) / kg
Starane	081406-37-3				1.2E-02			kg-1,4DCB-e (to soil) / kg
Styrene	000100-42-5	1.1E-05	7.1E-06			6.4E-06	2.3E-06	kg-1,4DCB-e (to soil) / kg
Sulprofos	035400-43-2				1.0E-02			kg-1,4DCB-e (to soil) / kg
t-Butyl alcohol	000075-65-0					1.9E-04	5.4E-05	kg-1,4DCB-e (to soil) / kg
Tebufenozide	112410-23-8				4.4E-01			kg-1,4DCB-e (to soil) / kg
Tebuthiuron	034014-18-1				8.2E-01			kg-1,4DCB-e (to soil) / kg
Terbacil	005902-51-2				3.6E-01			kg-1,4DCB-e (to soil) / kg
Terbufos	013071-79-9				1.1E+02			kg-1,4DCB-e (to soil) / kg
Terbuthylazin	005915-41-3				2.6E+00			kg-1,4DCB-e (to soil) / kg
Terbutryn	000886-50-0				5.1E+00			kg-1,4DCB-e (to soil) / kg
Thallium	007440-28-0	2.4E+00	1.8E+00	3.3E+00	3.7E+00	1.6E-21	6.9E-22	kg-1,4DCB-e (to soil) / kg
Thiabendazole	000148-79-8				1.8E+00			kg-1,4DCB-e (to soil) / kg
Thidiazuron	051707-55-2				5.4E+00			kg-1,4DCB-e (to soil) / kg
Thiobencarb	028249-77-6				1.5E+00			kg-1,4DCB-e (to soil) / kg
Thiodicarb	059669-26-0				4.7E+01			kg-1,4DCB-e (to soil) / kg
Thiophanat-methyl	023564-05-8				1.2E+00			kg-1,4DCB-e (to soil) / kg
Thiram	000137-26-8				1.7E+01			kg-1,4DCB-e (to soil) / kg
Tin	007440-31-5	1.8E-01	1.3E-01	2.5E-01	2.8E-01			kg-1,4DCB-e (to soil) / kg
Tin, ion	022537-50-4					1.7E-24	6.5E-24	kg-1,4DCB-e (to soil) / kg
Tolclophos-methyl	057018-04-9				5.1E-01			kg-1,4DCB-e (to soil) / kg
Toluene	000108-88-3	1.4E-05	1.2E-05			9.4E-06	1.3E-06	kg-1,4DCB-e (to soil) / kg
Toluene, 2,4,6-trinitro-	000118-96-7	7.7E+00	7.7E+00			5.8E-06	8.7E-08	kg-1,4DCB-e (to soil) / kg
Toluene, 2,4-dinitro-	000121-14-2	5.7E+00	5.5E+00			2.3E-03	3.4E-05	kg-1,4DCB-e (to soil) / kg
Toluene, 2,6-dinitro-	000606-20-2	1.0E+00	9.9E-01			1.0E-04	1.5E-06	kg-1,4DCB-e (to soil) / kg
Tralomethrin	066841-25-6				6.4E-01			kg-1,4DCB-e (to soil) / kg
Triadimefon	043121-43-3				1.2E+00			kg-1,4DCB-e (to soil) / kg
Triadimenol	055219-65-3				5.6E-01			kg-1,4DCB-e (to soil) / kg
Tri-allate	002303-17-5				4.3E-01			kg-1,4DCB-e (to soil) / kg
Triazofos	024017-47-8				4.7E+01			kg-1,4DCB-e (to soil) / kg
Tribufos	000078-48-8					1.9E-04	1.6E-04	kg-1,4DCB-e (to soil) / kg
Tributyltin compounds	(blank)					4.6E-01	7.3E-02	kg-1,4DCB-e (to soil) / kg
Trichlorfon	000052-68-6				3.9E+00			kg-1,4DCB-e (to soil) / kg
Triclopyr	055335-06-3				1.5E+00			kg-1,4DCB-e (to soil) / kg
Triethylene glycol	000112-27-6					8.5E-10	4.0E-11	kg-1,4DCB-e (to soil) / kg
Trifluralin	001582-09-8				6.2E-01			kg-1,4DCB-e (to soil) / kg
Triforine	026644-46-2				4.0E+00			kg-1,4DCB-e (to soil) / kg
Urea	(blank)				2.6E-02			kg-1,4DCB-e (to soil) / kg
Vanadium	007440-62-2	6.2E+00	4.6E+00	8.9E+00	9.8E+00			kg-1,4DCB-e (to soil) / kg
Vanadium, ion	022541-77-1					3.7E-21	2.7E-21	kg-1,4DCB-e (to soil) / kg
Vinclozolin	050471-44-8				4.8E-01			kg-1,4DCB-e (to soil) / kg
Vinyl acetate	000108-05-4	1.1E-04	7.7E-05					kg-1,4DCB-e (to soil) / kg
Xylene	001330-20-7	8.4E-06	6.7E-06			5.8E-06	1.7E-06	kg-1,4DCB-e (to soil) / kg

		Impact Factors						
		Air		Soil		Water		
Substance	CAS	high pop / unspecified	low. pop.	agricultural	industrial / unspecified	freshwater / unspecified	ocean	
Zinc	007440-66-6	3.6E+00	1.3E+00	1.1E+00	5.2E+00			kg-1,4DCB-e (to soil) / kg
Zinc, ion	023713-49-7					6.7E-23	1.7E-22	kg-1,4DCB-e (to soil) / kg
Zineb	012122-67-7				7.2E-01			kg-1,4DCB-e (to soil) / kg

Human Toxicity Potential

		Impact Factors						
		Air		Soil		Water		
Substance	CAS	high pop / unspecified	low. pop.	agricultural	industrial / unspecified	freshwater / unspecified	ocean	
1,4-Dioxane	000123-91-1	4.2E-01	4.7E-02			1.5E-01	3.9E-03	kg-1,4DCB-e (to urban air) / kg
1-Butanol	000071-36-3					1.8E-02	4.0E-04	kg-1,4DCB-e (to urban air) / kg
2,4,5-T	000093-76-5				1.7E+00			kg-1,4DCB-e (to urban air) / kg
2,4-D	000094-75-7				3.8E-01			kg-1,4DCB-e (to urban air) / kg
2-Acetylaminofluorene	000053-96-3	1.1E+02	6.9E+01					kg-1,4DCB-e (to urban air) / kg
2-Benzothiazolethiol	000149-30-4	2.9E-01	2.6E-01			1.4E-01	3.0E-04	kg-1,4DCB-e (to urban air) / kg
2-Butenal	004170-30-3	1.7E+01	7.8E-01			1.3E+00	8.1E-03	kg-1,4DCB-e (to urban air) / kg
Abamectin	071751-41-2				4.5E+01			kg-1,4DCB-e (to urban air) / kg
Acenaphthene	000083-32-9					8.5E-02	1.8E-04	kg-1,4DCB-e (to urban air) / kg
Acephate	030560-19-1				9.4E+01			kg-1,4DCB-e (to urban air) / kg
Acetaldehyde	000075-07-0	4.9E+00	2.2E-01					kg-1,4DCB-e (to urban air) / kg
Acetamide	000060-35-5	6.3E-01	2.1E-01			3.8E-02	9.4E-06	kg-1,4DCB-e (to urban air) / kg
Acetaminophen	000103-90-2	5.4E-01	4.4E-02	2.4E-01		5.8E-01		kg-1,4DCB-e (to urban air) / kg
Acetone	000067-64-1	1.5E-01	1.9E-02			8.8E-03	6.0E-04	kg-1,4DCB-e (to urban air) / kg
Acetonitrile	000075-05-8	4.7E-01	5.8E-02			4.8E-02	8.7E-03	kg-1,4DCB-e (to urban air) / kg
Acetophenone	000098-86-2	2.9E-01	2.7E-02			1.7E-02	7.4E-04	kg-1,4DCB-e (to urban air) / kg
Acifluorfen	050594-66-6				4.8E-01			kg-1,4DCB-e (to urban air) / kg
Acrolein	000107-02-8	6.2E+03	2.3E+02					kg-1,4DCB-e (to urban air) / kg
Acrylamide	000079-06-1	3.9E+02	2.9E+01			4.9E+00	1.2E-03	kg-1,4DCB-e (to urban air) / kg
Acrylic acid	000079-10-7	3.7E+02	1.1E+01			1.5E-02	3.5E-06	kg-1,4DCB-e (to urban air) / kg
Acrylonitrile	000107-13-1					5.3E+00	6.7E-01	kg-1,4DCB-e (to urban air) / kg
Aldehydes, unspecified	(blank)	8.3E+01	1.6E+01					kg-1,4DCB-e (to urban air) / kg
Aldicarb	000116-06-3				2.6E+02			kg-1,4DCB-e (to urban air) / kg
Allyl chloride	000107-05-1	1.0E+01	4.9E-01			5.9E-01	3.4E-02	kg-1,4DCB-e (to urban air) / kg
Alpha-cypermethrin	067375-30-8				1.7E+00			kg-1,4DCB-e (to urban air) / kg
Aluminum phosphide	(blank)				3.4E+01			kg-1,4DCB-e (to urban air) / kg
Amitraz	033089-61-1				4.9E+00			kg-1,4DCB-e (to urban air) / kg
Aniline	000062-53-3	3.9E+00	7.9E-01			6.4E-01	1.5E-04	kg-1,4DCB-e (to urban air) / kg
Aniline, 3,4-dichloro-	000095-76-1	0.0E+00	0.0E+00	0.0E+00		0.0E+00		kg-1,4DCB-e (to urban air) / kg
Aniline, p-chloro-, hydrochloride	020265-96-7	3.6E+01	3.5E+01			2.7E+00	6.4E-04	kg-1,4DCB-e (to urban air) / kg
Anthracene	000120-12-7	3.6E-01	1.0E-01		5.1E-02	3.4E-03	1.5E-05	kg-1,4DCB-e (to urban air) / kg
Antimony	007440-36-0	4.9E+03	3.0E+02	1.8E+02	2.0E+02	8.6E+01	1.5E-19	kg-1,4DCB-e (to urban air) / kg
Arsenic	007440-38-2	1.5E+03	1.5E+02	1.4E+02	1.6E+02			kg-1,4DCB-e (to urban air) / kg
Arsenic, ion	017428-41-0					1.3E+03	7.1E-20	kg-1,4DCB-e (to urban air) / kg
Asulam	003337-71-1				3.0E-03			kg-1,4DCB-e (to urban air) / kg
Atrazine	001912-24-9				2.3E+00			kg-1,4DCB-e (to urban air) / kg
Azinphos-methyl	000086-50-0				7.2E-01			kg-1,4DCB-e (to urban air) / kg
Barium	007440-39-3	2.6E+02	3.6E+01	4.9E+01	5.8E+01	2.5E+01	1.7E-20	kg-1,4DCB-e (to urban air) / kg
Bendiocarb	022781-23-3				3.4E+00			kg-1,4DCB-e (to urban air) / kg
Benomyl	017804-35-2				1.2E-03			kg-1,4DCB-e (to urban air) / kg
Bentazone	025057-89-0				2.5E+00			kg-1,4DCB-e (to urban air) / kg
Benzaldehyde	000100-52-7	7.8E-01	4.0E-02			2.5E-02	7.8E-04	kg-1,4DCB-e (to urban air) / kg
Benzenamine, 2-methoxy-5-nitro-	000099-59-2	3.0E+00	1.5E+00			4.5E-01	2.1E-03	kg-1,4DCB-e (to urban air) / kg
Benzene	000071-43-2	1.4E+00	3.6E-01			3.6E-01	7.0E-02	kg-1,4DCB-e (to urban air) / kg
Benzene, (epoxyethyl)-	000096-09-3	2.3E+00	2.1E-01					kg-1,4DCB-e (to urban air) / kg
Benzene, 1,2,4-trichloro-	000120-82-1	6.5E+00	2.6E+00			4.6E+00	1.5E+00	kg-1,4DCB-e (to urban air) / kg
Benzene, 1,2-dichloro-	000095-50-1	1.2E+00	5.0E-01			5.6E-01	2.9E-01	kg-1,4DCB-e (to urban air) / kg
Benzene, 1,3-dinitro-	000099-65-0	4.2E+02	2.1E+02			2.9E+01	1.5E-01	kg-1,4DCB-e (to urban air) / kg
Benzene, 1,4-dichloro-	000106-46-7	1.0E+00	4.8E-01			6.0E-01	2.8E-01	kg-1,4DCB-e (to urban air) / kg
Benzene, chloro-	000108-90-7					7.8E-01	3.3E-01	kg-1,4DCB-e (to urban air) / kg
Benzene, ethyl-	000100-41-4	8.1E-02	7.2E-03			2.2E-02	9.5E-04	kg-1,4DCB-e (to urban air) / kg
Benzene, hexachloro-	000118-74-1	9.2E+02	8.4E+02					kg-1,4DCB-e (to urban air) / kg
Benzene, pentachloro-	000608-93-5	1.6E+02	1.1E+02					kg-1,4DCB-e (to urban air) / kg
Benzidine	000092-87-5	9.6E+01	1.1E+01					kg-1,4DCB-e (to urban air) / kg
Benzidine, 3,3'-dichloro-	000091-94-1	6.1E+01	8.2E+01					kg-1,4DCB-e (to urban air) / kg
Benzo(a)pyrene	000050-32-8	5.4E+01	1.1E+02					kg-1,4DCB-e (to urban air) / kg
Benzotrichloride	000098-07-7	6.4E+02	7.8E+01					kg-1,4DCB-e (to urban air) / kg
Benzyl chloride	000100-44-7	4.1E+00	5.9E-01			4.7E-01	1.1E-02	kg-1,4DCB-e (to urban air) / kg
Beryllium	007440-41-7	3.6E+05	1.5E+04	2.3E+01	2.7E+01	9.2E+00	2.0E-17	kg-1,4DCB-e (to urban air) / kg
Bifenthrin	082657-04-3				4.8E+00			kg-1,4DCB-e (to urban air) / kg
Biphenyl, 4-amino-	000092-67-1	3.6E+01	8.9E+00					kg-1,4DCB-e (to urban air) / kg
Bis(2-chloro-1-methylethyl)ether	000108-60-1	7.0E+00	1.0E+00			1.2E+00	4.3E-01	kg-1,4DCB-e (to urban air) / kg
Bis(2-chloroethyl)ether	000111-44-4	2.1E+01	2.3E+00			8.1E-01	6.5E-03	kg-1,4DCB-e (to urban air) / kg
Bis(chloromethyl)ether	000542-88-1					9.1E+03	1.5E+03	kg-1,4DCB-e (to urban air) / kg
Bisphenol A	000080-05-7	2.0E+00	4.4E-02	1.2E-02		2.5E+00		kg-1,4DCB-e (to urban air) / kg
Bitertanol	055179-31-2				9.4E-01			kg-1,4DCB-e (to urban air) / kg
Botran	000099-30-9				1.2E+00			kg-1,4DCB-e (to urban air) / kg
Bromate	015541-45-4					6.4E+00	1.5E-03	kg-1,4DCB-e (to urban air) / kg
Bromoform	000075-25-2	1.3E+01	5.9E+00					kg-1,4DCB-e (to urban air) / kg
Bromoxynil	001689-84-5				4.7E-01			kg-1,4DCB-e (to urban air) / kg
Buprofezin	069327-76-0				4.9E+00			kg-1,4DCB-e (to urban air) / kg
Butadiene	000106-99-0	5.0E+00	1.1E-01					kg-1,4DCB-e (to urban air) / kg

		Impact Factors						
		Air		Soil		Water		
Substance	CAS	high pop / unspecified	low. pop.	agricultural	industrial / unspecified	freshwater / unspecified	ocean	
Butadiene, hexachloro-	000087-68-3	1.8E+01	1.6E+01					kg-1,4DCB-e (to urban air) / kg
Butene, 1,4-dichloro-2- (trans)	000110-57-6	8.6E+01	2.9E+00					kg-1,4DCB-e (to urban air) / kg
C.I. direct blue 218	028407-37-6					1.2E-02	1.5E-04	kg-1,4DCB-e (to urban air) / kg
C.I. disperse yellow 3	002832-40-8	8.1E-01	6.8E-01			1.6E+00	4.4E-03	kg-1,4DCB-e (to urban air) / kg
Cadmium	007440-43-9	5.0E+03	3.5E+02	1.6E+02	5.2E+02			kg-1,4DCB-e (to urban air) / kg
Cadmium, ion	022537-48-0					3.3E+01	5.1E-20	kg-1,4DCB-e (to urban air) / kg
Caprolactam	000105-60-2	7.1E-01	1.1E-01			1.4E-02	3.0E-06	kg-1,4DCB-e (to urban air) / kg
Captan	000133-06-2				7.2E-04			kg-1,4DCB-e (to urban air) / kg
Carbamic acid, ethyl ester	000051-79-6	1.1E+00	4.8E-01			5.5E-02	4.7E-05	kg-1,4DCB-e (to urban air) / kg
Carbendazim	010605-21-7				2.5E-01			kg-1,4DCB-e (to urban air) / kg
Carbofuran	001563-66-2				1.2E+01			kg-1,4DCB-e (to urban air) / kg
Carbon disulfide	000075-15-0	4.8E+01	1.0E+01					kg-1,4DCB-e (to urban air) / kg
Carboxin	005234-68-4				1.7E-01			kg-1,4DCB-e (to urban air) / kg
Catechol	000120-80-9	4.2E-01	9.7E-02			7.3E-02	1.4E-05	kg-1,4DCB-e (to urban air) / kg
Chlorendic acid	000115-28-6	7.9E+00	8.4E+00					kg-1,4DCB-e (to urban air) / kg
Chlorfenvinphos	000470-90-6				3.2E+02			kg-1,4DCB-e (to urban air) / kg
Chlorimuron-ethyl	090982-32-4				9.8E-02			kg-1,4DCB-e (to urban air) / kg
Chlorine	007782-50-5	2.1E+02	2.1E+02			1.7E+02	4.0E+01	kg-1,4DCB-e (to urban air) / kg
Chlormequat	007003-89-6				7.6E-01			kg-1,4DCB-e (to urban air) / kg
Chloroform	000067-66-3	3.1E+01	2.1E+01			2.0E+01	1.2E+01	kg-1,4DCB-e (to urban air) / kg
Chloromethyl methyl ether	000107-30-2	2.4E+01	2.3E+00					kg-1,4DCB-e (to urban air) / kg
Chlorothalonil	001897-45-6				3.9E+00			kg-1,4DCB-e (to urban air) / kg
Chlorpropham	000101-21-3				2.3E+00			kg-1,4DCB-e (to urban air) / kg
Chlorpyrifos	002921-88-2				1.3E+01			kg-1,4DCB-e (to urban air) / kg
Chlorsulfuron	064902-72-3				6.1E-01			kg-1,4DCB-e (to urban air) / kg
Chromium VI	018540-29-9	5.5E+03	2.3E+02	6.8E-02	7.5E-02	8.0E-02	2.8E-20	kg-1,4DCB-e (to urban air) / kg
Clofentezine	074115-24-5				1.8E+00			kg-1,4DCB-e (to urban air) / kg
Cobalt	007440-48-4	4.3E+03	1.9E+02	3.8E-16	3.8E-19	1.9E-19	1.2E-19	kg-1,4DCB-e (to urban air) / kg
Copper	007440-50-8	1.5E+00	8.9E-02	3.1E-02	8.9E-02			kg-1,4DCB-e (to urban air) / kg
Cumene	000098-82-8	1.1E-01	1.1E-02			2.8E-02	1.1E-03	kg-1,4DCB-e (to urban air) / kg
Cupferron	000135-20-6					2.4E+00	5.8E-04	kg-1,4DCB-e (to urban air) / kg
Cyanazine	021725-46-2				1.5E+00			kg-1,4DCB-e (to urban air) / kg
Cyanide	000057-12-5	6.7E+00	1.2E+00			7.2E-01	7.0E-02	kg-1,4DCB-e (to urban air) / kg
Cyclohexane	000110-82-7					2.1E-02	6.2E-03	kg-1,4DCB-e (to urban air) / kg
Cyclohexene, 4-vinyl-	000100-40-3	7.0E-01	1.4E-02			1.8E+00	2.3E-02	kg-1,4DCB-e (to urban air) / kg
Cyclohexylamine	000108-91-8	1.4E+00	5.0E-02			1.2E-01	8.4E-04	kg-1,4DCB-e (to urban air) / kg
Cyclopentadiene, hexachloro-	000077-47-4	1.5E+03	4.8E+02					kg-1,4DCB-e (to urban air) / kg
Cyfluthrin	068359-37-5				3.3E+00			kg-1,4DCB-e (to urban air) / kg
Cypermethrin	052315-07-8				1.4E+03			kg-1,4DCB-e (to urban air) / kg
Cyromazine	066215-27-8				1.4E+02			kg-1,4DCB-e (to urban air) / kg
Daminozide	001596-84-5				3.7E-02			kg-1,4DCB-e (to urban air) / kg
Decabromodiphenyl oxide	001163-19-5	8.2E+02	1.0E+03			1.5E-03	2.1E-04	kg-1,4DCB-e (to urban air) / kg
Deltamethrin	052918-63-5				1.8E-01			kg-1,4DCB-e (to urban air) / kg
Diazinon	000333-41-5				5.0E+01			kg-1,4DCB-e (to urban air) / kg
Dicamba	001918-00-9				5.4E-01			kg-1,4DCB-e (to urban air) / kg
Dichlorvos	000062-73-7				6.3E+00			kg-1,4DCB-e (to urban air) / kg
Dicofol	000115-32-2				1.6E+01			kg-1,4DCB-e (to urban air) / kg
Difenzoquat	043222-48-6				4.1E-01			kg-1,4DCB-e (to urban air) / kg
Diflubenzuron	035367-38-5				4.4E-01			kg-1,4DCB-e (to urban air) / kg
Diglycidyl resorcinol ether	000101-90-6	6.2E+00	4.4E+00					kg-1,4DCB-e (to urban air) / kg
Dihydrosafrole	000094-58-6	4.2E-01	2.2E-02					kg-1,4DCB-e (to urban air) / kg
Dimethipin	055290-64-7				5.1E+00			kg-1,4DCB-e (to urban air) / kg
Dimethoate	000060-51-5				1.0E+00			kg-1,4DCB-e (to urban air) / kg
Dimethylcarbamyl chloride	000079-44-7	2.2E+02	6.9E+01					kg-1,4DCB-e (to urban air) / kg
Dinoseb	000088-85-7				1.5E+02			kg-1,4DCB-e (to urban air) / kg
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	(blank)	1.0E+08	1.1E+08					kg-1,4DCB-e (to urban air) / kg
Diphenamid	000957-51-7				2.2E-01			kg-1,4DCB-e (to urban air) / kg
Dipropylthiocarbamic acid S-ethyl ester	000759-94-4	1.4E+01	5.4E-01		8.9E-01	2.1E+00	5.3E-02	kg-1,4DCB-e (to urban air) / kg
Diquat dibromide	000085-00-7				4.4E+01			kg-1,4DCB-e (to urban air) / kg
Disulfoton	000298-04-4				2.0E+01			kg-1,4DCB-e (to urban air) / kg
Dithianon	003347-22-6				1.2E+00			kg-1,4DCB-e (to urban air) / kg
Diuron	000330-54-1				1.9E+00			kg-1,4DCB-e (to urban air) / kg
Dodine	002439-10-3				4.6E-02			kg-1,4DCB-e (to urban air) / kg
Endosulfan	000115-29-7				1.6E+00			kg-1,4DCB-e (to urban air) / kg
Endothall	000145-73-3				4.5E-02			kg-1,4DCB-e (to urban air) / kg
Epichlorohydrin	000106-89-8	1.3E+02	1.7E+01					kg-1,4DCB-e (to urban air) / kg
Ethane, 1,1,1,2-tetrachloro-	000630-20-6	1.1E+01	7.1E+00					kg-1,4DCB-e (to urban air) / kg
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	000811-97-2	1.4E-01	1.4E-01					kg-1,4DCB-e (to urban air) / kg
Ethane, 1,1,2,2-tetrachloro-	000079-34-5	8.5E+00	2.5E+00			2.8E+00	6.7E-02	kg-1,4DCB-e (to urban air) / kg
Ethane, 1,1,2-trichloro-	000079-00-5	1.9E+02	9.5E+01					kg-1,4DCB-e (to urban air) / kg
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	000076-13-1	3.4E+00	3.4E+00					kg-1,4DCB-e (to urban air) / kg
Ethane, 1,1-dichloro-1-fluoro-, HCFC-141b	001717-00-6	8.5E-01	8.3E-01					kg-1,4DCB-e (to urban air) / kg
Ethane, 1,1-difluoro-, HFC-152a	000075-37-6	1.3E-02	1.1E-02					kg-1,4DCB-e (to urban air) / kg
Ethane, 1,2-dibromo-	000106-93-4	1.5E+02	6.2E+01			6.4E+01	3.1E+01	kg-1,4DCB-e (to urban air) / kg
Ethane, 1,2-dichloro-	000107-06-2	3.3E+01	1.7E+01			1.7E+01	1.4E+01	kg-1,4DCB-e (to urban air) / kg

		Impact Factors						
		Air		Soil		Water		
Substance	CAS	high pop / unspecified	low. pop.	agricultural	industrial / unspecified	freshwater / unspecified	ocean	
Ethane, 1-chloro-1,1-difluoro-, HCFC-142b	000075-68-3	3.7E-02	3.5E-02					kg-1,4DCB-e (to urban air) / kg
Ethane, 2,2-dichloro-1,1,1-trifluoro-, HCFC-123	000306-83-2	3.8E-01	3.2E-01					kg-1,4DCB-e (to urban air) / kg
Ethane, 2-chloro-1,1,1-trifluoro-, HCFC-133a	000075-88-7	1.5E+01	1.4E+01					kg-1,4DCB-e (to urban air) / kg
Ethane, chloro-	000075-00-3	2.4E-01	1.1E-01			9.5E-02	1.7E-02	kg-1,4DCB-e (to urban air) / kg
Ethane, hexachloro-	000067-72-1					1.2E+03	6.7E+02	kg-1,4DCB-e (to urban air) / kg
Ethanol	000064-17-5	1.4E-02	1.4E-03					kg-1,4DCB-e (to urban air) / kg
Ethanol, 2-butoxy-	000111-76-2					7.9E-02	3.0E-04	kg-1,4DCB-e (to urban air) / kg
Ethanol, 2-methoxy-	000109-86-4					1.6E-01	3.2E-02	kg-1,4DCB-e (to urban air) / kg
Ethene, chloro-	000075-01-4	1.5E+01	1.4E+00			4.7E+00	9.3E-01	kg-1,4DCB-e (to urban air) / kg
Ethene, dichloro- (trans)	000156-60-5					4.7E+00	3.2E+00	kg-1,4DCB-e (to urban air) / kg
Ethene, tetrachloro-	000127-18-4	7.7E+01	4.9E+01			4.8E+01	2.8E+01	kg-1,4DCB-e (to urban air) / kg
Ethene, trichloro-	000079-01-6	1.8E-01	3.3E-02			5.5E-02	1.5E-02	kg-1,4DCB-e (to urban air) / kg
Ethephon	016672-87-0				4.9E+00			kg-1,4DCB-e (to urban air) / kg
Ethion	000563-12-2				4.0E+00			kg-1,4DCB-e (to urban air) / kg
Ethoprop	013194-48-4				1.1E+03			kg-1,4DCB-e (to urban air) / kg
Ethyl acrylate	000140-88-5	8.2E-01	4.1E-02			5.0E-02	2.3E-03	kg-1,4DCB-e (to urban air) / kg
Ethylene glycol	000107-21-1					6.9E-03	7.1E-06	kg-1,4DCB-e (to urban air) / kg
Ethylene oxide	000075-21-8	1.0E+01	2.0E+00			1.9E+00	2.0E-01	kg-1,4DCB-e (to urban air) / kg
Fenamiphos	022224-92-6				8.8E+00			kg-1,4DCB-e (to urban air) / kg
Fenarimol	060168-88-9				1.6E+01			kg-1,4DCB-e (to urban air) / kg
Fenbuconazole	114369-43-6				2.1E+00			kg-1,4DCB-e (to urban air) / kg
Fenitrothion	000122-14-5				3.2E+00			kg-1,4DCB-e (to urban air) / kg
Fenpropathrin	039515-41-8				7.5E-01			kg-1,4DCB-e (to urban air) / kg
Fenpropimorph	067306-03-0				1.9E+01			kg-1,4DCB-e (to urban air) / kg
Fentin acetate	000900-95-8				1.7E+01			kg-1,4DCB-e (to urban air) / kg
Fentin hydroxide	000076-87-9				1.1E+01			kg-1,4DCB-e (to urban air) / kg
Fenvalerate	051630-58-1				2.1E+00			kg-1,4DCB-e (to urban air) / kg
Fluometuron	002164-17-2				2.5E-01			kg-1,4DCB-e (to urban air) / kg
Fluoranthene	000206-44-0	1.9E+00	4.2E-01			3.7E+00	4.2E-03	kg-1,4DCB-e (to urban air) / kg
Flusilazole	085509-19-9				6.0E+00			kg-1,4DCB-e (to urban air) / kg
Flutolanil	066332-96-5				1.5E-01			kg-1,4DCB-e (to urban air) / kg
Folpet	000133-07-3				1.4E+00			kg-1,4DCB-e (to urban air) / kg
Fomesafen	072178-02-0				5.0E+00			kg-1,4DCB-e (to urban air) / kg
Fonofos	000944-22-9				5.3E+00			kg-1,4DCB-e (to urban air) / kg
Formaldehyde	000050-00-0	1.1E+02	2.2E+01			5.3E+00	1.4E-02	kg-1,4DCB-e (to urban air) / kg
Fosetyl-aluminium	039148-24-8				3.8E-02			kg-1,4DCB-e (to urban air) / kg
Glufosinate ammonium	077182-82-2				4.8E+00			kg-1,4DCB-e (to urban air) / kg
Glyphosate	001071-83-6				7.4E-04			kg-1,4DCB-e (to urban air) / kg
Hexaconazole	079983-71-4				8.9E+00			kg-1,4DCB-e (to urban air) / kg
Hexane	000110-54-3	1.3E+00	1.4E-01					kg-1,4DCB-e (to urban air) / kg
Hexazinone	051235-04-2				1.9E-01			kg-1,4DCB-e (to urban air) / kg
Hexythiazox	078587-05-0				7.3E-01			kg-1,4DCB-e (to urban air) / kg
Hydrazine	000302-01-2					1.3E+01	7.5E-02	kg-1,4DCB-e (to urban air) / kg
Hydrazine, methyl-	000060-34-4	5.4E+00	3.8E-01					kg-1,4DCB-e (to urban air) / kg
Hydrocarbons, aliphatic, alkanes, cyclic	(blank)	9.8E-03	3.4E-04					kg-1,4DCB-e (to urban air) / kg
Hydrocarbons, aromatic	(blank)	1.3E+00	3.5E-01			1.5E+01	2.5E+00	kg-1,4DCB-e (to urban air) / kg
Hydrocarbons, chlorinated	(blank)	5.2E+01	3.8E+01					kg-1,4DCB-e (to urban air) / kg
Hydrogen fluoride	007664-39-3	2.7E+02	8.2E+00					kg-1,4DCB-e (to urban air) / kg
Hydroquinone	000123-31-9	2.8E+00	8.3E-01			1.1E-02	7.8E-07	kg-1,4DCB-e (to urban air) / kg
Imazalil	035554-44-0				6.2E-01			kg-1,4DCB-e (to urban air) / kg
Imazaquin	081335-37-7				2.7E-02			kg-1,4DCB-e (to urban air) / kg
Iprodion	036734-19-7				4.1E-02			kg-1,4DCB-e (to urban air) / kg
Isofenphos	025311-71-1				1.9E+01			kg-1,4DCB-e (to urban air) / kg
Isoxaben	082558-50-7				5.0E-01			kg-1,4DCB-e (to urban air) / kg
Kresoxim-methyl	143390-89-0				3.5E-01			kg-1,4DCB-e (to urban air) / kg
Lactofen	077501-63-4				4.9E+01			kg-1,4DCB-e (to urban air) / kg
Lead	007439-92-1	4.7E+03	2.0E+02	6.9E-01	2.3E+00	6.1E+00	7.5E-21	kg-1,4DCB-e (to urban air) / kg
Lindane	000058-89-9				1.0E+02			kg-1,4DCB-e (to urban air) / kg
Linuron	000330-55-2				1.2E+01			kg-1,4DCB-e (to urban air) / kg
Malathion	000121-75-5				8.4E-03			kg-1,4DCB-e (to urban air) / kg
Maleic anhydride	000108-31-6	4.1E+00	1.4E-01			6.6E-06	1.3E-09	kg-1,4DCB-e (to urban air) / kg
Maleic hydrazide	000123-33-1				1.4E-01			kg-1,4DCB-e (to urban air) / kg
Mancozeb	008018-01-7				8.4E-04			kg-1,4DCB-e (to urban air) / kg
Maneb	012427-38-2				4.0E-02			kg-1,4DCB-e (to urban air) / kg
Manganese	007439-96-5	2.8E+03	1.2E+02	1.4E-02	1.5E-02	5.3E+00	7.0E-20	kg-1,4DCB-e (to urban air) / kg
MCPA	000094-74-6				3.8E+00			kg-1,4DCB-e (to urban air) / kg
MCPB	000094-81-5				1.3E-01			kg-1,4DCB-e (to urban air) / kg
m-Cresol	000108-39-4	9.4E-01	7.4E-02		5.5E-02	8.9E-02	1.6E-04	kg-1,4DCB-e (to urban air) / kg
Mepiquat chloride	024307-26-4				2.8E-01			kg-1,4DCB-e (to urban air) / kg
Mercury	007439-97-6	5.0E+05	3.9E+04	5.5E+03	5.8E+03	5.0E+02	1.5E+03	kg-1,4DCB-e (to urban air) / kg
Metalaxil	057837-19-1				8.9E-01			kg-1,4DCB-e (to urban air) / kg
Methacrylic acid, methyl ester	000080-62-6	7.6E+00	2.7E-01			2.4E-01	6.3E-02	kg-1,4DCB-e (to urban air) / kg
Methamidophos	010265-92-6				7.7E+00			kg-1,4DCB-e (to urban air) / kg
Methane, bromo-, Halon 1001	000074-83-9	3.5E+03	2.6E+03					kg-1,4DCB-e (to urban air) / kg
Methane, chlorodifluoro-, HCFC-22	000075-45-6	7.1E-02	6.7E-02					kg-1,4DCB-e (to urban air) / kg

		Impact Factors						
		Air		Soil		Water		
Substance	CAS	high pop / unspecified	low. pop.	agricultural	industrial / unspecified	freshwater / unspecified	ocean	
Methane, chlorofluoro-, HCFC-31	000593-70-4	1.8E+01	1.4E+01					kg-1,4DCB-e (to urban air) / kg
Methane, dichloro-, HCC-30	000075-09-2	2.3E+01	1.3E+01			1.1E+01	3.4E+00	kg-1,4DCB-e (to urban air) / kg
Methane, dichlorodifluoro-, CFC-12	000075-71-8	5.7E+02	5.7E+02					kg-1,4DCB-e (to urban air) / kg
Methane, monochloro-, R-40	000074-87-3	5.5E+00	4.2E+00					kg-1,4DCB-e (to urban air) / kg
Methane, tetrachloro-, CFC-10	000056-23-5	6.0E+03	5.8E+03			5.8E+03	4.7E+03	kg-1,4DCB-e (to urban air) / kg
Methane, trichlorofluoro-, CFC-11	000075-69-4	6.7E+01	6.6E+01					kg-1,4DCB-e (to urban air) / kg
Methanol	000067-56-1	2.5E-01	2.0E-02			5.4E-03	1.5E-04	kg-1,4DCB-e (to urban air) / kg
Methidathion	000950-37-8				2.3E+00			kg-1,4DCB-e (to urban air) / kg
Methiocarb	002032-65-7				2.9E+00			kg-1,4DCB-e (to urban air) / kg
Methomyl	016752-77-5				7.7E+00			kg-1,4DCB-e (to urban air) / kg
Methyl ethyl ketone	000078-93-3					2.8E-03	5.4E-05	kg-1,4DCB-e (to urban air) / kg
Metiram	009006-42-2				4.1E+00			kg-1,4DCB-e (to urban air) / kg
Metolachlor	051218-45-2				7.0E-01			kg-1,4DCB-e (to urban air) / kg
Metribuzin	021087-64-9				7.2E-01			kg-1,4DCB-e (to urban air) / kg
Metsulfuron-methyl	074223-64-6				6.8E-02			kg-1,4DCB-e (to urban air) / kg
Mevinfos	007786-34-7				3.3E-01			kg-1,4DCB-e (to urban air) / kg
Molinate	002212-67-1				8.7E+00			kg-1,4DCB-e (to urban air) / kg
Molybdenum	007439-98-7	1.3E+02	1.3E+01	1.2E+01	1.5E+01	7.9E+01	6.6E-21	kg-1,4DCB-e (to urban air) / kg
Molybdenum trioxide	001313-27-5	8.9E+01	7.6E+01			1.1E+01	1.6E-02	kg-1,4DCB-e (to urban air) / kg
Monochloramine	(blank)	1.9E+00	8.0E-01			7.1E-02	1.6E-05	kg-1,4DCB-e (to urban air) / kg
m-Phenylenediamine	000108-45-2	3.3E+00	9.4E-01			5.2E-01	5.5E-05	kg-1,4DCB-e (to urban air) / kg
Myclobutanil	088671-89-0				2.6E-01			kg-1,4DCB-e (to urban air) / kg
Naled	000300-76-5				1.8E+01			kg-1,4DCB-e (to urban air) / kg
Naphthalene	000091-20-3	8.2E+00	3.7E-01			2.1E+00	3.3E-02	kg-1,4DCB-e (to urban air) / kg
Napropamide	015299-99-7				1.5E-01			kg-1,4DCB-e (to urban air) / kg
Nickel	007440-02-0	4.1E+02	1.8E+01	1.5E-01	8.8E-01			kg-1,4DCB-e (to urban air) / kg
Nickel, ion	014701-22-5					9.8E-01	1.1E-20	kg-1,4DCB-e (to urban air) / kg
Nitrilotriacetic acid	000139-13-9	2.9E-02	6.7E-03			1.9E-03	4.0E-07	kg-1,4DCB-e (to urban air) / kg
Nitrobenzene	000098-95-3	1.3E+02	1.8E+01			1.8E+01	2.1E+00	kg-1,4DCB-e (to urban air) / kg
Nitroglycerin	000055-63-0	7.0E-01	3.1E-01			8.8E-02	1.1E-04	kg-1,4DCB-e (to urban air) / kg
N-Methylolacrylamide	000924-42-5	5.4E+00	2.4E+00			4.1E-01	8.9E-05	kg-1,4DCB-e (to urban air) / kg
N-Nitrosodiethylamine	000055-18-5	6.4E+03	6.6E+02					kg-1,4DCB-e (to urban air) / kg
N-Nitrosodimethylamine	000062-75-9	2.3E+03	3.2E+01	2.4E+02		1.6E+02		kg-1,4DCB-e (to urban air) / kg
N-Nitrosodiphenylamine	000086-30-6	6.6E-01	2.8E-01			2.1E+00	1.7E-02	kg-1,4DCB-e (to urban air) / kg
N-Nitrosopiperidine	000100-75-4	1.6E+01	3.7E+00					kg-1,4DCB-e (to urban air) / kg
Norflurazon	027314-13-2				2.8E-01			kg-1,4DCB-e (to urban air) / kg
o-Cresol	000095-48-7	1.2E+00	6.9E-02			4.1E-02	1.0E-04	kg-1,4DCB-e (to urban air) / kg
o-Phenylenediamine dihydrochloride	000615-28-1	1.2E-01	1.3E-01					kg-1,4DCB-e (to urban air) / kg
Oryzalin	019044-88-3				3.1E-01			kg-1,4DCB-e (to urban air) / kg
o-Toluidine hydrochloride	000636-21-5	7.3E-01	7.0E-02					kg-1,4DCB-e (to urban air) / kg
Oxazepam	000604-75-1	1.6E+01	1.6E+00	8.0E+00		3.0E+01		kg-1,4DCB-e (to urban air) / kg
Oxydiazon	019666-30-9				1.1E+01			kg-1,4DCB-e (to urban air) / kg
Oxyfluorfen	042874-03-3				4.9E+01			kg-1,4DCB-e (to urban air) / kg
Paclobutrazol	076738-62-0				3.6E-01			kg-1,4DCB-e (to urban air) / kg
PAH, polycyclic aromatic hydrocarbons	130498-29-2	2.1E+01	3.5E+01			2.0E+00	3.1E-02	kg-1,4DCB-e (to urban air) / kg
Parathion	000056-38-2				1.2E+00			kg-1,4DCB-e (to urban air) / kg
Parathion, methyl	000298-00-0				8.4E+00			kg-1,4DCB-e (to urban air) / kg
p-Cresidine	000120-71-8	2.3E-01	2.5E-02			2.4E-01	3.9E-04	kg-1,4DCB-e (to urban air) / kg
Pendimethalin	040487-42-1				1.1E+00			kg-1,4DCB-e (to urban air) / kg
Permethrin	052645-53-1	1.9E+00	6.6E-02	6.7E-01		4.4E+00		kg-1,4DCB-e (to urban air) / kg
Phenmedipham	013684-63-4				9.5E-04			kg-1,4DCB-e (to urban air) / kg
Phenol	000108-95-2	9.3E-01	6.7E-02			1.1E-02	1.6E-05	kg-1,4DCB-e (to urban air) / kg
Phenol, 2,4,5-trichloro-	000095-95-4	2.6E+00	1.6E+00			3.9E-01	4.1E-04	kg-1,4DCB-e (to urban air) / kg
Phenol, 2,4,6-trichloro-	000088-06-2	7.9E-01	8.0E-01			1.5E-01	1.2E-04	kg-1,4DCB-e (to urban air) / kg
Phenol, 2,4-dichloro-	000120-83-2	3.7E+02	2.0E+02			8.6E-01	2.7E-03	kg-1,4DCB-e (to urban air) / kg
Phenol, 2,4-dimethyl-	000105-67-9	2.8E+00	1.0E-01			4.8E-01	1.1E-03	kg-1,4DCB-e (to urban air) / kg
Phenol, 2,4-dinitro-	000051-28-5	6.7E+01	9.0E+01			2.5E+00	8.3E-04	kg-1,4DCB-e (to urban air) / kg
Phenol, pentachloro-	000087-86-5	4.4E+01	3.5E+01					kg-1,4DCB-e (to urban air) / kg
Phenytoin	000057-41-0	1.1E+01	5.4E-01	5.2E-01		1.7E+01		kg-1,4DCB-e (to urban air) / kg
Phorate	000298-02-2				3.9E+00			kg-1,4DCB-e (to urban air) / kg
Phosmet	000732-11-6				3.5E-01			kg-1,4DCB-e (to urban air) / kg
Phosphorus	007723-14-0	1.9E+04	1.5E+04	9.5E+03	9.5E+03	9.4E+03	1.1E+03	kg-1,4DCB-e (to urban air) / kg
Phthalate, butyl-benzyl-	000085-68-7					2.9E-02	1.7E-04	kg-1,4DCB-e (to urban air) / kg
Phthalate, dibutyl-	000084-74-2					1.9E-01	5.8E-04	kg-1,4DCB-e (to urban air) / kg
Phthalate, dimethyl tere-	000120-61-6	2.3E+00	4.8E-01					kg-1,4DCB-e (to urban air) / kg
Phthalate, dioctyl-	000117-81-7					6.6E+00	1.5E+00	kg-1,4DCB-e (to urban air) / kg
Picloram	001918-02-1				5.1E-01			kg-1,4DCB-e (to urban air) / kg
Pirimicarb	023103-98-2				2.2E-01			kg-1,4DCB-e (to urban air) / kg
Pirimiphos methyl	029232-93-7				2.7E+00			kg-1,4DCB-e (to urban air) / kg
Polychlorinated biphenyls	001336-36-3	3.9E+01	3.8E+01			1.1E+02	8.8E+00	kg-1,4DCB-e (to urban air) / kg
Prochloraz	067747-09-5				5.6E+00			kg-1,4DCB-e (to urban air) / kg
Procymidone	032809-16-8				4.6E-01			kg-1,4DCB-e (to urban air) / kg
Profenofos	041198-08-7				3.0E+00			kg-1,4DCB-e (to urban air) / kg
Prometryn	007287-19-6				3.9E-01			kg-1,4DCB-e (to urban air) / kg
Pronamide	023950-58-5				2.2E+00			kg-1,4DCB-e (to urban air) / kg
Propachlor	001918-16-7				2.0E-01			kg-1,4DCB-e (to urban air) / kg

		Impact Factors						
		Air		Soil		Water		
Substance	CAS	high pop / unspecified	low. pop.	agricultural	industrial / unspecified	freshwater / unspecified	ocean	
Propamocarb	024579-73-5				3.9E-01			kg-1,4DCB-e (to urban air) / kg
Propane sultone	001120-71-4	5.2E+01	3.1E+01					kg-1,4DCB-e (to urban air) / kg
Propane, 1,2-dibromo-3-chloro-	000096-12-8	1.1E+03	3.0E+02					kg-1,4DCB-e (to urban air) / kg
Propane, 1,2-dichloro-	000078-87-5	2.7E+02	1.2E+02			1.2E+02	1.0E+02	kg-1,4DCB-e (to urban air) / kg
Propane, 2-nitro-	000079-46-9	8.2E+00	2.1E+00			2.0E+00	1.0E+00	kg-1,4DCB-e (to urban air) / kg
Propanil	000709-98-8				4.6E-01			kg-1,4DCB-e (to urban air) / kg
Propargite	002312-35-8				1.1E+00			kg-1,4DCB-e (to urban air) / kg
Propargyl alcohol	000107-19-7	2.0E+01	1.6E+00					kg-1,4DCB-e (to urban air) / kg
Propene, 1,3-dichloro-	000542-75-6	1.2E+03	6.6E+01		3.3E+01	1.0E+01	1.8E-01	kg-1,4DCB-e (to urban air) / kg
Propene, 1-chloro-1-	000590-21-6	3.7E+01	2.3E+00					kg-1,4DCB-e (to urban air) / kg
Propham	000122-42-9				3.3E-02			kg-1,4DCB-e (to urban air) / kg
Propiconazole	060207-90-1				2.7E+00			kg-1,4DCB-e (to urban air) / kg
Propoxur	000114-26-1				1.8E+00			kg-1,4DCB-e (to urban air) / kg
Propylene oxide	000075-56-9	4.3E+01	6.4E+00			4.6E+00	2.6E-01	kg-1,4DCB-e (to urban air) / kg
Pyrene	000129-00-0	3.4E+00	2.6E+00			1.7E-01	3.1E-04	kg-1,4DCB-e (to urban air) / kg
Pyridine	000110-86-1	1.1E+02	1.3E+01			1.6E+00	5.6E-04	kg-1,4DCB-e (to urban air) / kg
Pyriproxyfen	095737-68-1				1.5E-01			kg-1,4DCB-e (to urban air) / kg
Quizalofop ethyl ester	076578-14-8				3.0E+00			kg-1,4DCB-e (to urban air) / kg
Resmethrin	010453-86-8				6.2E-01			kg-1,4DCB-e (to urban air) / kg
Rotenone	000083-79-4				6.8E+00			kg-1,4DCB-e (to urban air) / kg
Safrole	000094-59-7	1.1E-01	2.3E-02					kg-1,4DCB-e (to urban air) / kg
Selenium	007782-49-2	5.8E+02	5.4E+02	1.1E+03	1.2E+03	2.9E+02	3.1E-19	kg-1,4DCB-e (to urban air) / kg
Sethoxydim	074051-80-2				1.1E-01			kg-1,4DCB-e (to urban air) / kg
Silver	007440-22-4	1.8E+04	1.1E+03	7.1E+02	7.9E+02			kg-1,4DCB-e (to urban air) / kg
Silver, ion	014701-21-4					3.9E+01	2.2E-19	kg-1,4DCB-e (to urban air) / kg
Simazine	000122-34-9				1.2E+01			kg-1,4DCB-e (to urban air) / kg
Sodium azide	026628-22-8	3.2E+01	6.5E+00			3.8E-01	8.3E-05	kg-1,4DCB-e (to urban air) / kg
Styrene	000100-42-5	3.2E+00	8.1E-02			4.0E-01	2.9E-02	kg-1,4DCB-e (to urban air) / kg
t-Butyl alcohol	000075-65-0					5.6E-01	7.5E-02	kg-1,4DCB-e (to urban air) / kg
t-Butyl methyl ether	001634-04-4	3.1E-01	4.8E-02			5.3E-02	2.8E-02	kg-1,4DCB-e (to urban air) / kg
Tebufenozide	112410-23-8				9.7E-01			kg-1,4DCB-e (to urban air) / kg
Tebuthiuron	034014-18-1				2.7E-01			kg-1,4DCB-e (to urban air) / kg
Teflubenzuron	083121-18-0				1.8E+01			kg-1,4DCB-e (to urban air) / kg
Terbacil	005902-51-2				5.3E-01			kg-1,4DCB-e (to urban air) / kg
Terbufos	013071-79-9				5.0E+02			kg-1,4DCB-e (to urban air) / kg
Terbutryn	000886-50-0				4.4E+01			kg-1,4DCB-e (to urban air) / kg
Thallium	007440-28-0	2.2E+02	3.2E+01	4.5E+01	5.2E+01	1.1E+02	1.3E-20	kg-1,4DCB-e (to urban air) / kg
Thiabendazole	000148-79-8				4.1E-01			kg-1,4DCB-e (to urban air) / kg
Thifensulfuron-methyl	079277-27-3				1.7E+00			kg-1,4DCB-e (to urban air) / kg
Thioacetamide	000062-55-5	8.2E+00	1.4E+00					kg-1,4DCB-e (to urban air) / kg
Thiobencarb	028249-77-6				3.8E+00			kg-1,4DCB-e (to urban air) / kg
Thiodicarb	059669-26-0				1.3E+00			kg-1,4DCB-e (to urban air) / kg
Thiophanat-methyl	023564-05-8				8.1E-02			kg-1,4DCB-e (to urban air) / kg
Thiourea	000062-56-6	6.8E-01	1.8E-01			7.0E-02	1.5E-05	kg-1,4DCB-e (to urban air) / kg
Thiram	000137-26-8				7.2E-01			kg-1,4DCB-e (to urban air) / kg
Tin, ion	022537-50-4					7.7E-03	1.3E-22	kg-1,4DCB-e (to urban air) / kg
Tolclophos-methyl	057018-04-9				3.6E+00			kg-1,4DCB-e (to urban air) / kg
Toluene	000108-88-3	8.2E-01	8.0E-02			7.0E-02	8.6E-03	kg-1,4DCB-e (to urban air) / kg
Toluene diisocyanate	026471-62-5	1.3E+04	2.9E+03			1.2E+04	4.4E+02	kg-1,4DCB-e (to urban air) / kg
Toluene, 2,4,6-trinitro-	000118-96-7	5.1E+02	6.2E+02			4.1E-02	1.5E-05	kg-1,4DCB-e (to urban air) / kg
Toluene, 2,4-diamine	000095-80-7	1.6E+01	4.2E+01					kg-1,4DCB-e (to urban air) / kg
Toluene, 2,4-dinitro-	000121-14-2	1.5E+02	1.3E+02			5.5E-01	9.9E-04	kg-1,4DCB-e (to urban air) / kg
Toluene, 2-chloro-	000095-49-8	7.1E+00	1.5E+00			1.7E+00	2.6E-01	kg-1,4DCB-e (to urban air) / kg
Toluene, dinitro-	025321-14-6	2.9E+01	1.4E+01			5.5E+00	8.7E-02	kg-1,4DCB-e (to urban air) / kg
Tralomethrin	066841-25-6				1.3E+01			kg-1,4DCB-e (to urban air) / kg
Triadimefon	043121-43-3				1.3E+00			kg-1,4DCB-e (to urban air) / kg
Triadimenol	055219-65-3				3.7E-01			kg-1,4DCB-e (to urban air) / kg
Tri-allate	002303-17-5				2.7E+00			kg-1,4DCB-e (to urban air) / kg
Triasulfuron	082097-50-5				4.4E+00			kg-1,4DCB-e (to urban air) / kg
Triazofos	024017-47-8				3.4E+02			kg-1,4DCB-e (to urban air) / kg
Tribufos	000078-48-8					1.9E+03	9.4E+01	kg-1,4DCB-e (to urban air) / kg
Tributyltin compounds	(blank)					3.5E+02	4.0E+00	kg-1,4DCB-e (to urban air) / kg
Trichlorfon	000052-68-6				1.6E-01			kg-1,4DCB-e (to urban air) / kg
Triethyl amine	000121-44-8	7.9E-01	1.5E-02					kg-1,4DCB-e (to urban air) / kg
Trifluralin	001582-09-8				8.4E+00			kg-1,4DCB-e (to urban air) / kg
Triforine	026644-46-2				5.8E+00			kg-1,4DCB-e (to urban air) / kg
Vanadium	007440-62-2	2.8E+03	1.3E+02	1.9E+01	2.1E+01			kg-1,4DCB-e (to urban air) / kg
Vanadium, ion	022541-77-1					2.5E+01	8.8E-20	kg-1,4DCB-e (to urban air) / kg
Vinclozolin	050471-44-8				2.7E+00			kg-1,4DCB-e (to urban air) / kg
Vinyl acetate	000108-05-4	3.4E+00	1.3E-01					kg-1,4DCB-e (to urban air) / kg
Xylene	001330-20-7	1.0E+00	5.8E-02			7.5E-02	1.5E-02	kg-1,4DCB-e (to urban air) / kg
Zinc	007440-66-6	1.4E+01	1.3E+00	5.9E-01	2.7E+00			kg-1,4DCB-e (to urban air) / kg
Zinc, ion	023713-49-7					5.0E-01	2.2E-22	kg-1,4DCB-e (to urban air) / kg
Zineb	012122-67-7				1.4E-01			kg-1,4DCB-e (to urban air) / kg

APPENDIX D Statistical Analysis Summaries

Traditional Infrastructure Mix

Statistical summary for Monte-Carlo analysis results shown in Figure 6

Impact category	Mean	Median	2.5th %ile	97.5th %ile	SD	CV	Std.err.of mean
Freshwater Extraction	0.1350	0.1350	0.1300	0.1390	0.0023	0.02	0.001
Eutrophication Potential	0.0851	0.0852	0.0668	0.1060	0.0097	0.11	0.009
Marine Ecotoxicity Potential	0.0239	0.0226	0.0169	0.0357	0.0069	0.29	0.022
Freshwater Ecotoxicity Potential	0.0027	0.0027	0.0022	0.0034	0.0003	0.10	0.008
Terrestrial Ecotoxicity Potential	0.0111	0.0111	0.0087	0.0133	0.0012	0.11	0.008
Global Warming Potential	0.0105	0.0101	0.0090	0.0149	0.0014	0.13	0.010
Ozone Depletion Potential	0.0311	0.0279	0.0105	0.0792	0.0169	0.54	0.042
Fossil Fuel Depletion	0.0039	0.0039	0.0037	0.0042	0.0001	0.03	0.003
Human Toxicity Potential	0.0057	0.0057	0.0055	0.0059	0.0001	0.02	0.001

Future Infrastructure Mix

Statistical summary for Monte-Carlo analysis results shown in Figure 6

Impact category	Mean	Median	2.5th %ile	97.5th %ile	SD	CV	Std.err.of mean
Freshwater Extraction	0.1380	0.1390	0.1340	0.1420	0.0021	0.02	0.003
Eutrophication Potential	0.1820	0.1780	0.1500	0.2400	0.0231	0.13	0.024
Marine Ecotoxicity Potential	0.0653	0.0629	0.0511	0.0969	0.0101	0.16	0.029
Freshwater Ecotoxicity Potential	0.0086	0.0086	0.0075	0.0107	0.0006	0.07	0.013
Terrestrial Ecotoxicity Potential	0.0310	0.0310	0.0261	0.0351	0.0026	0.08	0.015
Global Warming Potential	0.0444	0.0441	0.0407	0.0492	0.0023	0.05	0.010
Ozone Depletion Potential	0.0777	0.0709	0.0202	0.1590	0.0303	0.39	0.072
Fossil Fuel Depletion	0.0200	0.0197	0.0188	0.0223	0.0009	0.05	0.008
Human Toxicity Potential	0.0212	0.0211	0.0206	0.0223	0.0004	0.02	0.004

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