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CHALLENGES AND OPPORTUNITIES IN LCA – THE WATER INDUSTRY EXAMPLE

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ABSTRACT

Challenges like population growth and climate change are maintaining a high level of dynamism in the water industry, resulting in large capital investments and the consideration of alternatives to conventional water supplies. In this environment, LCA is appreciated as a useful planning tool, but it has not yet achieved its full potential due to the lack of a national sustainability framework and other factors. In this paper, examples of recent LCAs in the water industry are discussed. The practical justification and resourcing of LCAs are examined. In addition, two case studies are presented illustrating how LCA can assist the planning process and the degree to which hybridisation presents a methodological challenge to traditional process LCA. Finally, the implications of the new WSAA Sustainability Framework for the future of LCA practice are discussed.

Keywords: sustainability framework, water industry, hybrid LCA

1. SETTING THE SCENE

The water industry is changing rapidly and is investing in new infrastructure to cope with population growth and climate change. Australia's population is projected to grow from 19 million in 2000 to 23 million in 2020 [1]. Rainfall in existing catchments has reduced significantly since 1950 in what some scientists believe is a result of human-induced climate change [2]. To respond to these and other challenges, Sydney Water alone has spent an average of approximately half a billion dollars per year on new capital works [3] and expects to invest $1.3 billion in a desalination plant if dam levels reach 30% [4]. One would imagine that this is a perfect environment for the growth and application of LCA. The method has indeed found a home in the water industry and this paper will describe several successful LCA projects which reflect the industry’s growth. However, the full potential for LCA has not yet been achieved. This paper will examine some of the practical and methodological reasons why.

2. AUSTRALIAN WATER INDUSTRY LCAs

It should be noted that this is not a complete review. The authors are aware of LCAs completed in the water industry which are not published because they relate to politically contentious issues, and others which might be defined as greenhouse gas LCAs, but which are not labelled nor recognised as such. What follows is a discussion of key published LCAs.

The first ISO14040-compliant water industry LCA was a Sydney Water / CWWT study of alternative biosolids handling options [5]. Performed in 1999 and published in 2002, this study was also a first for its use of human health impact assessment factors that had been tuned to Australian conditions. Completing this study enabled Sydney Water planners to get a grip on LCA, what goes into it, and what kinds of results can be expected. This emboldened the organisation to embark on a comprehensive LCA of its overall business in 2001, the WaterPlan 21 LCA. Presented to the ALCAS conference in 2002 [6] and published in 2004 [7], this was the first LCA in the world to cover an entire water system for city with several million citizens, from the dams to the treated effluent outfalls.

In 2003, with the help of RMIT, Yarra Valley Water released its first LCA: a study of the sustainability of rainwater tanks [8]. The study interestingly demonstrated the significance of material and energy demands associated with using rainwater tanks, though the normalisation suggested their benefits outweigh the burdens. Yarra Valley Water has been very productive in the LCA field since then, performing studies on water-sensitive urban design for a greenfields area [9], the relative merits of pressure and gravity sewerage [10], and two studies on alternatives in pump and meter selection [11]. Yarra Valley Water currently has a project examining water services for a backlog area.

Sydney Water has also continued to produce LCAs: comparisons of alternative digestion technologies [12], alternatives in effluent disinfection [12], and alternatives in greenfields servicing [13]. The latter was a collaboration with a coalition of environmental groups called the Peak Environment Non-Government Organisations. The PENGOs' study examined some more radical alternatives than the Sydney Water had previously analysed in this way. Sydney Water is now pursuing two additional projects involving LCA of biosolids treatment alternatives.

South Australian Water has also been an Australian LCA pioneer, teaming with CWWT and Sydney Water in 2002 to perform its first LCA – a retrospective comparison of treatment alternatives at the Bolivar STP. Subsequently, SA Water has examined water supply alternatives (including desalination) for the Eyre Peninsula [14] and alternative reticulation options in its Adelaide water supply, which will be discussed further in this paper.

3. EXAMPLE – HOPE VALLEY RESERVOIR LCA

3.1 Introduction

SA Water was faced with a practical engineering decision – whether to keep repairing the Torrens Aqueduct, part of the connection between Kangaroo Creek Reservoir and to the Hope Valley Reservoir. Originally constructed in the 1870s, this 4.5 km of concrete open channels and tunnels had the benefits of operating under gravity, but presented increasing risks to public safety and the continuity of the water supply. An increase in emergency flow capacity was also desirable.

Three principal solutions were seen to the challenge of upgrading this part of Adelaide's water supply infrastructure [15]. The aqueduct could be refurbished: the channel covered, relined and repaired in some locations. The principal alternative was replacement of the aqueduct, with either a new pipeline or a pipeline laid within the existing aqueduct. These options were compared on the basis of capital and operating costs, and social and environmental impacts. The LCA formed part of the assessment of environmental impacts and was included in the multicriteria assessment.

One of the main differences between the options was the requirement for booster pumping in the new pipeline option during periods of high demand. In the new pipeline option analysed in the LCA, a booster pump was to be installed in an old building previously used to house chlorination equipment. For an average daily flowrate of 80 ML/d, the new pipeline option and the aqueduct options would be able to cope with demand. But for higher flowrates the booster pump would be required in order to reach demand flows. This would mean operating the pump on an average of 165 days per year.

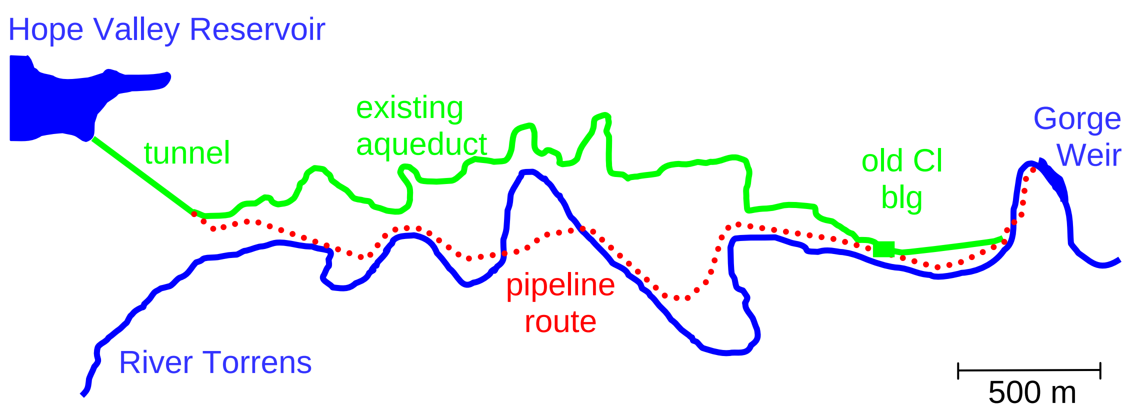


Figure 1: alternative delivery systems

Many LCAs of capital works options with considerable recurrent energy demands do not examine the energy consumed by the construction process. Since we expected that for one of our options (channel repair) the energy to be expended for the initial repair and further maintenance over its lifespan would represent a considerable proportion of the total environmental burden, we decided to include energy used during construction in the inventory.

Another feature of this LCA was a degree of uncertainty associated with the lifespan of the distribution infrastructure. Consequently we analysed the three systems on two timespans: 25 years and 100 years. The principal difference in the LCI between these scenarios was in that addition to its proportionally higher ongoing maintenance needs, a significant refurbishment of the channel option would be expected after 50 years of operation.

This LCA included six indicator categories: total energy consumption; contribution to climate change; eutrophication potential; photochemical oxidant formation potential; human toxicity potential and marine ecotoxicity potential.

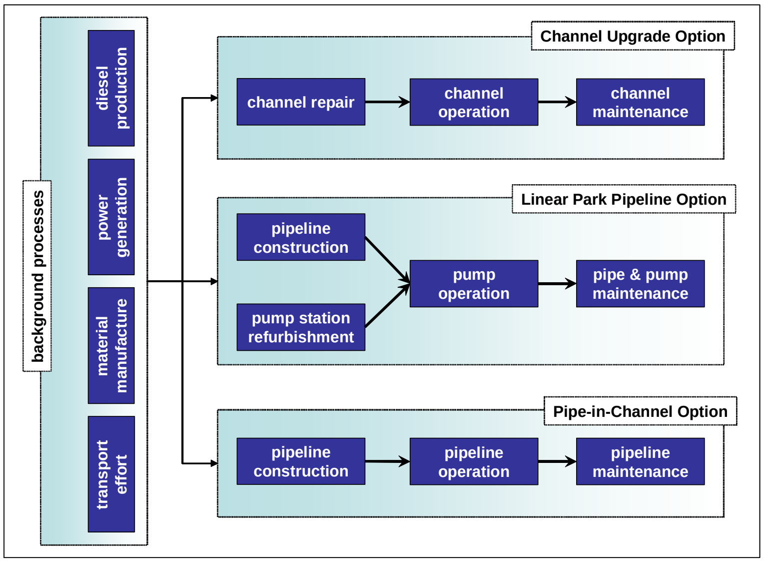


Figure 2: options considered in the LCA

3.2 Discussion of the results

The results of the LCIA are shown in Table 1. It is clear that despite operating as a peak pressure booster only, the pump in the new pipeline option played a dominant role in the comparison between the options. The two options making use of the existing channel performed better than the new pipeline option against all assessment categories, independently of the operational time frame of infrastructure. Over 100 years of operation, the pipe-in-channel option outperforms the other two options in all assessment categories. Over 25 years of operation, the comparison between the two channel-based options is less decisive. The channel repair option was superior in terms of energy consumption, eutrophication potential, photochemical oxidant potential and human toxicity potential, but the pipe-in-channel option was superior with respect to greenhouse gas emissions and marine ecotoxicity potential. On the other hand, when a standard error tolerance of 25% was applied to these results, it was only in the photochemical oxidant potential category that the channel repair option was superior over a 25 year timespan. When the period was extended to 100 years of operation, the pipe-in-channel option was significantly better in all assessment categories except eutrophication potential and photochemical oxidant potential. These results are shown graphically in Figures 1 and 2 with the results scaled relative to the pipe-in-channel option.

	channel repair option		**new pipeline option**		**pipe-in-channel option**		**units**
years of operation	**25**	**100**	**25**	**100**	**25**	**100**	
LCA indicator							
Total energy consumption	86	174	275	943	87	87	TJ
Greenhouse gas emissions	8.7	18	21	74	7.0	7.0	kt CO_2-e
Eutrophication potential	198	406	439	1061	292	292	t O_2-e
Photochemical oxidant potential	2.0	4.2	3.8	6.3	3.8	3.8	t C_2H_4-e
Human toxicity potential	6.2	13	12	40	6.7	6.7	t DCB-e
Marine ecotoxicity potential	20	41	62	236	18	18	kt DCB-e

Table 1: LCIA results

Looking at some of the impact category results for the 25 year analysis in detail we can see that in the case of the channel repair option most of the greenhouse gas emissions are embodied in materials, such as concrete (42%) and steel (46%), while only a small portion of the emissions result from the use of diesel-fuelled construction equipment. Contrary to the authors' expectations, this contrasts with the results of the pipe-in-channel option, where the energy associated with the construction process is a significant portion of the overall performance of this option. The performance of the pipeline option is determined by operational energy inputs for water pumping, i.e. 82% of total contribution to climate change, and less energy demand occurs during construction or the manufacturing of materials, i.e. 10% and 9% respectively. The strong connection between energy consumption and contributions to climate change is due to the source of the vast majority of the energy being fossil-fuelled electrical power stations.

Figure 3: Relative performance - 25 years

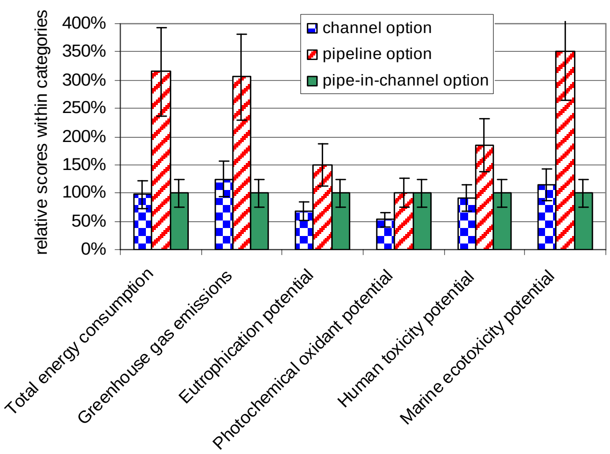
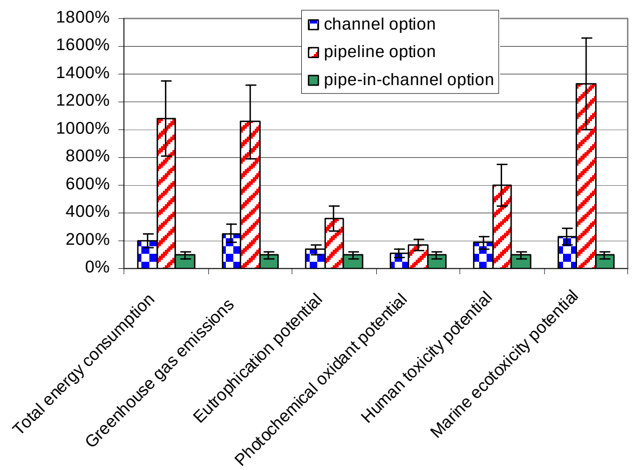


Figure 4: Relative performance - 100 years



In many LCAs the consumption of electricity has a controlling influence on several impact categories (for example, greenhouse gas emissions – see Table 2), but in this and other LCAs we also find impact categories that are dominated by other inventory items. An example of this is shown in Table 3 below. The production of materials causes the largest contribution to the eutrophication potential of the channel repair option due to nitrogen oxide emissions during the production of concrete and steel. Nitrogen oxide emissions are also responsible for construction impacts for the other two options. Almost half of the environmental burden is due to electricity generation in the new pipeline option, while the construction process dominates the production of materials in the pipe-in-channel option. The production and combustion of diesel fuel in the construction equipment are the key processes.

Option		Channel repair	New pipeline	Pipe-in-channel
Total GHG emissions	**kt CO_2-e/a**	**8.7**	**21**	**7.0**
construction materials	%	88	8.5	70
construction energy	%	11	9.6	30
operational materials	%	0.9	0	0
operational energy	%	0.5	82	0
Total GHG emissions	%	100	100	100

Table 2: Contributions to climate change by activity

Option		Channel repair	New pipeline	Pipe-in-channel
Total EP	**t O_2/a**	**198**	**439**	**292**
construction materials	%	50	4.7	28
construction energy	%	47	48	72
operational materials	%	0.5	0	0
operational energy	%	2.1	47	0
Total EP	%	100	100	100

Table 3: Eutrophication potential by activity

3.3 Outcomes

The LCA was considered by SA Water in conjunction with analysis of social impacts, capital and operating costs and a detailed risk assessment. While generally speaking the LCA indicated that the channel repair or pipe-in-channel options were preferable to the new pipeline, cost and risk characteristics favoured the latter. For this reason, the pipeline design was further refined. The LCA indicated that the key issue with the design was the need for booster pumping. The pipeline design diameter was increased by 75% to 1.75 m, with the consequence that the frictional headloss from one end to the other was significantly reduced and the need for a booster pump was eliminated. The SA Government has since announced that the new pipeline is the preferred option.

Under the preferred option, the aqueduct land reserve becomes surplus to SA Water's requirements. This reserve, approximately 51 hectares in area, is highly valued by the local community and is a significant green buffer area in metropolitan Adelaide. A recent survey noted the presence of 2.3 hectares of native blue gum woodland, an asset valued highly due to its urban location. It is the stated intent of the Government to incorporate the surplus aqueduct reserve into the Linear Park system and preserve it for future generations [16].

4. LOOKING FORWARD – METHODOLOGICAL ISSUES

Changes to LCA methods will present a challenge to LCA practitioners. We may, for example, expect LCA impact assessment methodologies to be continuously refined as new climatological and toxicological data are produced to enhance our assessment of greenhouse gas and organic chemical emissions. For those who favour them, category aggregation processes such as Eco-Indicator 99 will presumably continue to be debated and developed. Another key development is the idea of LCA hybridisation with input-output analysis [17]. This area is still highly dynamic but holds the promise of combining the best of both worlds – greater responsiveness to unique elements of the processes being evaluated (thanks to the use of process LCA data) and greater system completeness (thanks to input-output modelling of supply chains). CWWT has been collaborating with the University of Sydney to develop this general area further. This paper will summarise a recent case-study.

4.1 Hybrid LCA application to Sydney Water

In this case study, the authors developed a tiered hybrid LCA model and applied it to a functional unit of *the operations of Sydney Water in 2002/03*. First, process-based LCA results [7] were scaled to the reference year using the ratio of total water supplied in the previous study and in the reference year. 'Water use' was also redefined to be consistent with the definition of water use in the input-output analysis (i.e. losses, leakage and use within Sydney Water operations, rather than total water distributed). The authors constructed an input-output model of the Australian economy using data from the Australian Bureau of Statistics [18]. The input-output model was extended to carry out a hybrid analysis according to the method described by Rowley [19]. Environmental emissions data for 2002/03 were obtained from the National Pollutant Inventory (NPI) [20] and were allocated to industry sectors and emission compartments. Primary energy usage and greenhouse gas emissions data have been allocated to industry sectors in previous work [17], as have water use data [21]. Sydney Water expenditure data for 2001/02 were derived from Lenzen *et al.* [22]. For all methods, characterisation for human toxicity and ecotoxicity was carried out using updated characterisation factors from Lundie *et al.* [23].

Preliminary analysis demonstrated that in general, the results of a pure input-output analysis were considerably less reliable than the process-based results. This was especially true for the estimation of zero-order burdens. Therefore, a modified approach was used to calculate the input-output-based results. This modified approach is technically a form of tiered hybrid analysis, with the interface set between the zero-order and higher-order processes. In fact, this type of approach has been used to improve the accuracy of Australian input-output analysis in the literature (e.g. in much of the work of Lenzen) but has not been promoted as a hybrid approach. Thus, the input-output results are not purely input-output-based, because the zero-order environmental burdens were estimated from Sydney Water publications [24] and Sydney Water reports to the NPI [20].

As shown in Figure 5, the input-output-based result for freshwater aquatic ecotoxicity potential was smaller than the process-based result. Inspection of the data revealed that the process-based result was dominated by copper emitted to agricultural soil during application of biosolids (48%), and freshwater nickel emissions by inland wastewater treatment plants (22%). By contrast, 99.9% of the zero-order result in the input-output result was caused by chlorine emissions to freshwater. The input-output analysis did not capture the more significant downstream emissions. The hybrid analysis is able to compensate for the truncation error of the process analysis whilst retaining the downstream burdens to give a more complete picture of the total burden.

The results for marine aquatic ecotoxicity were interesting because in the initial analysis, the zero-order burden in the input-output analysis was calculated to be approximately 120 times the magnitude of the process-based result. Inspection of the datasets revealed that this was primarily attributable to fluoride compounds emitted to water. Fluoride compounds were not reported in the process analysis but appear in the NPI substance list so the results of analysis based on these two different datasets in their original states are not comparable. This serves as a reminder that data consistency is critical to comparing options and that strategic assessment tools like LCA are better-suited to comparative analyses (between systems or products) than to drawing conclusions about the absolute impacts of one process. To overcome this problem in the analysis, the datasets were standardised by removing emissions of fluoride compounds to water by the water and wastewater industry sector from the NPI dataset. The revised results reveal a large contribution from higher-order processes in the input-output-based result.

The usefulness of the hybrid model is demonstrated to its full potential in the case of both of these indicators, by adding the truncated portion of the input-output (upstream) burden to the process burden, independent of the relative magnitude of those two results.

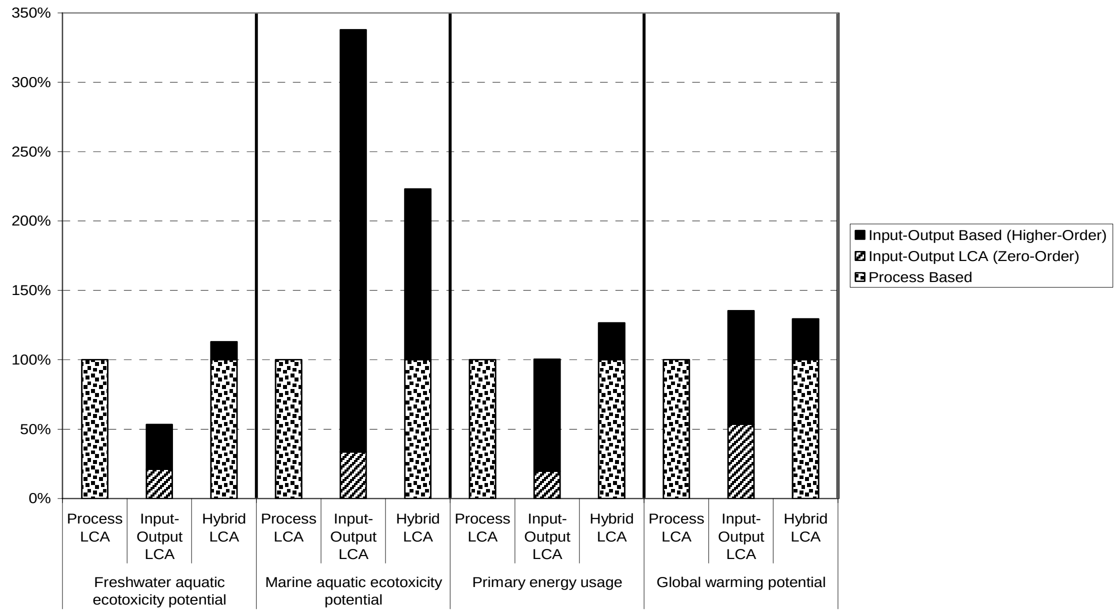


Figure 5: Comparison of process LCA, I/O LCA and hybrid LCA results

In the case of primary energy usage, the hybrid analysis is also particularly useful. Had the process and input-output analyses been carried out independently of the hybrid, the analyst would most likely have concluded that since the results were almost identical, they both gave a reasonably ‘correct’ answer. However, the hybrid analysis reveals that this similarity is in fact coincidental, and that a more accurate result is around 30% greater than either of the other results.

This case study supports the largely theoretical claims in the literature about the relative merits and drawbacks of process and input-output analysis. Each method has the potential to highlight different aspects of the system. This is particularly useful in the water services industry where there has been much debate about whether the greatest environmental burden is caused by nutrient discharge (zero-order) or electricity use (higher-order).

From an environmental management perspective, it would be beneficial to consider the three methodologies in parallel. In particular, this study has highlighted the potential for differences in reporting frameworks to cause massive anomalies between methods if they are applied without detailed interpretation. This suggests that there may be a high level of analytical risk associated with application of input-output tools by non-specialists.

4.2 LCA in a sustainability framework

The Water Services Association of Australia (WSAA) hired a consortium of researchers representing members of the Centre for Water and Waste Technology and the School of Civil and Environmental Engineering (UNSW, Sydney), Sustainable Water Division of the NSW Department of Commerce (Sydney) and Chalmers Industriteknik (Chalmers University, Sweden), to develop a sustainability framework for evaluating urban water systems. The objective of the project was to develop a common methodology for evaluating the overall sustainability of alternative options for urban water systems. This includes large-scale options for cities as well as configurations of water sensitive urban designs or single high rise developments.

The project produced a report outlining a six-phase planning process for the evaluation of alternatives [25]. It is not the purpose of this paper to summarise the report (see [26]), but key elements to note are that it concludes that community engagement (rather than mere information) is a critical part of the planning process, and that the evaluation of alternatives needs to be underpinned by an adequate level of quantitative assessment. Tools such as LCA are recommended by the framework to empower stakeholders weighing up the competing advantages of alternative options. Practitioners may need to be prepared to explain LCA to a wider audience than before.

It is worth noting here that the framework is not prescriptive about the level of detail at which an LCA ought to be performed as part of the planning process. At the simplest level, an LCA could consist of an analysis of the embodied greenhouse gas emissions of materials and energy used, normalised to the expected service life of the components of a product or process – a "greenhouse gas LCA". Such analysis is more widespread than preliminary or full LCAs, and is often not called LCA as such. For relatively simple decisions, this may be an adequate level of strategic environmental assessment.

5. LOOKING FORWARD – PRACTICAL ISSUES

Fundamentally, LCA application has grown in the water industry because of internal interest rather than regulatory demand. Forward-looking engineers, environmental scientists and managers request them because they foresee the value LCA can add to the evaluation of alternatives and the improvement of option designs. In one case, a new graduate engineer arrived with a desire to ensure environmental issues could be considered as quantitatively as financial ones during the planning process. A bottom-up process of promoting the methodology ensued. In another case, it appears the arrival of a new CEO with a desire to enhance the organisation's sustainability rapidly facilitated the organisation's adoption of LCA processes, so the change was relatively top-driven. And when a few organisations start doing LCA, the others are forced to ask "Why don't we?" – encouraging lateral diffusion.

Institutional mentalities may be a key determinant in the success or otherwise of LCA application. Crisis situations sometimes lead to requests for LCA application, but the level of urgency associated with crisis mentalities makes it difficult to obtain meaningful results in the allowable timeframes. Nor is it easy to do LCA when decisionmakers already have a clear preference for an option and feel they just have to 'pass the environment test' by doing an LCA. Placing LCA in a general sustainability framework as the WSAA project has done should also help engineers and managers understand the role it can usefully play early in the planning process, and encourage proactive use rather than allowing the crisis management of sustainability issues seen recently in several Australian water supplies.

Resourcing LCAs is not always easy. The two principal approaches might be labelled "external" and "internal". In common with other "new" activities, water service providers begin with the external model - purchasing LCA consulting services while they learn about the method and how to do it. The advantages are that this avoids placing a burden on existing staff before the need has been demonstrated. The cost of completing such LCAs can be associated with the capital works budget – the money coming from the particular projects being assessed. This seems to be easier for organisations to justify than finding the money via operational budgets, although sometimes research and development budgets can be used.

Once it is clear to management that it intends to pursue LCA application, the external model may seem expensive and slow. Three Australian water service providers (Sydney Water, Yarra Valley Water and South Australian Water) have made the extra step of developing internal LCA providers. This has involved purchasing one of the two major LCA software packages (GaBi 4 in two cases, SimaPro in the other) and training staff in its application. The external service providers are called on from time to time to maintain the internal skill base (which is not difficult to justify when organisations have a training budget), or to assist with large projects when extra staff are needed.

6. CONCLUSIONS

The Australian water industry is adopting LCA at a moderate pace driven by its own high rate of change and the need to adequately evaluate alternative investments from an environmental perspective. It is natural that some of the larger water service providers have led the way, given the resources that LCA demands. Innovation in the methodology will change the service LCA practitioners offer, but the method is mature enough to be a necessary component within a sustainability framework for strategic planning. While in the past the key limitations to LCA application may have been a perception of its value, or data availability, today the rate-limiting issue is the ability of organisations to equip themselves with internal LCA skills.

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