Improving sustainability of engineering projects through the application of systems engineering

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ABSTRACT

This paper demonstrates the application of a systems engineering approach to handling the additional complexity introduced into engineering projects by including sustainability characteristics as design parameters. Systems engineering incorporates a 'top-down' approach that ensures that all the stakeholder requirements and their complex interdependencies are correctly identified and then reflected throughout the detailed development of the project.

The case study presented is the W2W Alliance upgrade of odour control facilities at Woodman Point wastewater treatment plant (WWTP) in Western Australia, where the largest biological scrubber system in Australia for this type of application is currently under construction, with biological scrubbers replacing the conventional chemical scrubbers previously used for odour control. This upgrade has resulted in a step-change in the WWTP's environmental footprint, since a biotrickling filter system consumes up to 95% less chemicals and can use reclaimed effluent (i.e. treated wastewater) in lieu of potable water, yet achieves comparable odour removal.

1. INTRODUCTION

Sustainability can be defined as living off the 'interest' of social, environmental and economic assets, rather than consuming the 'capital' of these assets. Achieving sustainable outcomes in engineering projects therefore requires assessing the interest and capital of these assets in order to understand how much will be requisitioned by an engineering activity. However, assessing social and environmental parameters involves considering wider, more complex systems, more stakeholders, more variables, variables that are either difficult or impossible to quantify, and longer timeframes. Much of this complexity lies outside the traditional engineering design methodology, therefore understanding these factors and shaping engineering practice to meet them generally requires a new approach.

2. SUSTAINABILITY

Sustainability conceptually rests on the realisation that our planet has a finite amount of resources. This realisation is manifested through changing societal expectations, growing scientific concern over the vitality of the environment, and changing pressures on both legislature and business. Fleming (2005) notes that despite reductions in emissions and improvements in the management of effluent and industrial waste, there are still pressing issues in Australia with respect to water and energy, which the country's viability.

Community expectations of sustainability are growing, but the meaning of sustainability is highly dependent on the application, in that its interpretation depends heavily on the time and space scales of the area of interest.

Sustainability has been broadly defined as “providing for the needs of the current generation without compromising the ability of future generations to meet their needs” (WECD 1987). This has also been expressed as “living off the interest rather than the capital” of economic, social and ecological capital stock.

This definition of sustainability signals a broader definition of the term ‘capital’, compared to the traditional definition, in which manufactured and human capital are grouped as ‘economic capital’. This traditional and narrow definition of capital has led to the current situation, in which only economic capital and interest required for engineering projects are forecast, monitored and reported as a matter of routine. Ekins (2003) broadens the definition of capital, and groups it into *manufactured*, *human* (labour), *social/organisational*, and *natural* (also referred to as environmental capital), yet there are no equivalent and established assessments for the requisition of environmental and social capital and interest for projects.

Sustainability has also largely been developed for and implemented at a policy (national/ regional) level – a spatial scale much larger than typical engineering projects. The implementation of sustainability at the engineering project level is also complicated by project boundaries (often politically rather than physically derived) and the dominant techno-economic planning of projects, which often ignores the socio-political realities of project delivery (Fleming 2005).

Despite the physical impact of engineering activities on economic, environmental and social capital, there is also less prior work on sustainability as applied at the engineering project level, compared to the policy level for which many sustainability theories and methodologies have been developed. Yet it is an area which warrants attention: Shen (2005) cites that 54% of total energy consumed in the USA is directly or indirectly related to buildings or construction activities.

Expectations are growing that engineering projects are assessed and optimised with respect to sustainability, yet this is not current practice, has limited or fragmented precedents, and is highly application dependent. This paper therefore proposes a new approach to engineering infrastructure projects, in which sustainability can be incorporated as a key aspect of design.

3. SYSTEMS ENGINEERING

The basic principles of systems engineering were first introduced in the telecommunications industry in the 1930s. These principles later developed into a detailed methodology for handling large and complex projects, mainly within the defence acquisition framework. However, in the last twenty years systems engineering has been adopted increasingly outside the defence and aerospace industries, and is today the preferred approach to handle complex of engineering projects in general.

Infrastructure projects are expensive, long term and multi-stakeholder activities, and are therefore complex. Project complexity is also increasing due to the growing size of the systems, in which collateral system interactions with the environment, which could be ignored when they were smaller, now become significant issues. This is particularly exacerbated by population growth and an increase in community engagement.

Infrastructure projects today also require more than one engineering discipline, and often disciplines from outside engineering, for their realisation, so there is a need for an overarching, coordinating and integrating activity. The rapid rate of change, both in technology and in society’s needs and expectations, leads to a demand for greater flexibility, a demand that conflicts with the traditional requirements for stability and durability.

The systems engineering methodology provides a solution to these issues by simplifying the design and delivery of engineering projects in the form of a structured, step-by-step and top-down approach to the project, in which the system complexity is handled in manageable parts (Aslaksen 2008).

As an example of the application to infrastructure, Mar (1999) highlighted the value of systems engineering in water resources engineering as a methodology to better coordinate the complex suite of needs and stakeholders inherent to water projects. He proposed that the fundamental systems engineering methodology comprises a process of Functions, Requirements, Answers and Test. *Functions* refers to the descriptions of the desired system behaviours, *Requirements* refers to the measurable criteria for these functions, *Answers* refers to the solutions designed to address the FR pair, and *Test* refers to the verification and validation tests and demonstrations, which measure how well the system meets its functions and requirements. This FRAT process is conducted at various levels of system, to the desired degree of decomposition, in a progressive process often referred to as the V-curve for development (Blanchard 2004). This creates a 'genealogy' for functions and requirements, which enforces vertical traceability of requirements.

The systems engineering methodology starts with the development of a clear and complete understanding of the problem space. This space includes not only the immediate problem, such as how to reduce odour, but all the issues associated with suppressing that problem and their interactions. This first step of viewing the problem space as a system of interacting issues is extremely important; an excellent discussion is given by Warfield (2006).

The systems approach then simplifies the system by starting at the top and structuring it on the basis of its internal and external interactions (a functional approach), rather than only on a physical basis (a hardware approach). A functional description of the system simplifies the behaviour of the system by allowing it to be optimised at the highest level, following which the functionality and requirements can be decomposed down to a desired level of detail (Aslaksen 2008). This improves the likelihood that the behaviour of the system, at any level of the hierarchy, complies with the stakeholders' requirements. The functional approach therefore complements, rather than displaces, the physical description of a system, since it focuses on behaviour of the system.

This functional basis for systems engineering also allows non-hardware subsystems (such as software or management subsystems) to be incorporated into a coherent description of a system, reducing the likelihood of oversight in design. The functional approach also allows examination of *emergent properties* – the properties that emerge from interacting sub-systems, which may be quite different to the behaviour of the individual subsystems. Therefore, such analysis minimises the likelihood of unexpected system behaviour. Systems engineering also offers clarity to a complex engineering project, since it fundamentally separates the requirements on the *product* (the system to be created) from the requirements on the *project* (the sequence of activities to create the product).

Sustainability increases the complexity of engineering projects, as it requires engineering designers to consider more than the immediate impact and statutory compliance of their designs. Sustainability of a system with respect to economic, environmental and social capital requires that the designer understands how much capital stock will be requisitioned by a design, and compares this to how much 'interest' flow such capital can sustain. This increases the number of stakeholders, and the time and space scales of the project. It also increases the number of performance measures of a project to include measures that may not have conventionally been measured or reported for typical engineering projects, and also implies that the system must have some flexibility in order to adapt to changes in requirements throughout the system life cycle.

Sustainability can be incorporated into the systems engineering methodology, as it implies new indicators for system performance, a broader set of stakeholders and examination of complete life cycle (standard in systems engineering). It can be incorporated into the methodology, much as constructability, operability, etc. are already considered in systems engineering. Systems engineering methodology is inherently capable of being tailored to an application and of incorporating different measures for a project.

Stakeholder identification is a key first step in the systems engineering methodology, and incorporating sustainability simply broadens the range of stakeholders to include all significant social, economic and environmental stakeholders in a project. Interpreting sustainability into a systems engineering context suggests that some stakeholders might be passive but still require consideration, such as the local catchment area.

Following stakeholder identification, a top-level functional model can be developed, in which system behaviour is identified and defined. The functional model can incorporate not only the economic (such as the desired return on capital), but also environmental and social aspects desired in the project and product functionality, for the complete life cycle of both. In the case of an odour control system for a wastewater treatment plant, the functionality of the system is strongly related its social impact. Therefore, the functional model allows the sustainability of a system to be considered at the highest level, and can incorporate system interactions with external systems, such as a local water catchment, or community.

Following development of a top-level functional model for the system, the requirements relating to system performance, constraints and interfaces can be developed, a process known as Requirements Elicitation. In Requirements Elicitation, the designer asks stakeholders for indicators related to a design aspect, such as impact on the water table, biodiversity, the local economy, and local social welfare, and so on. Requirements Elicitation is a structured process, involving interviews, questionnaires, and workshops, starting with a large set of requirements, wishes, and preconceived solutions and converging to a coherent and structured requirements set, through the elimination of inconsistencies, ambiguities, and unfounded assumptions. A description of one version of this process has been documented by Aslaksen (1996). The requirements for the project and the product would therefore be tailored to suit the spatial and temporal scales of both.

Bossel (2001) proposes that the viability and performance of a system be monitored by identifying representative indicators for the system and its subsystems, and that the performance of the system is based on these indicator states, in which the limit for the indicators might be a rate (e.g. rate of odour release) or a state (e.g. level of odour units at a stack outlet). The requirements set would consist of such indicators, and allow the designer to incorporate these into the planning, monitoring and tracking of the system.

System indicators would undoubtedly be a mixture of ‘hard’ quantitative indicators, readily accessible and objective, through to semi-quantitative or qualitative indicators, some of which are subjective. Despite this subjectivity, consideration of these indicators on an engineering project is itself a major piece of progress, since currently the techno-economic dimension is typically the sole basis for design, with environmental impact mitigation a “bolt-on” feature.

Adaptation to changing requirements throughout a project life cycle is important for sustainability, and systems engineering methodology also offers the means to handle the dynamic nature of sustainability requirements. These changes arise from society’s changing understanding and acceptance of sustainability, resulting in new legislation and increasing community pressure, and also because sustainability aspects of a project may often only reveal themselves as the project progresses. Evolution of the requirements is handled very effectively by the change management process within systems engineering, which captures the propagation of the effects of such changes throughout the system.

The systems engineering methodology is therefore able to incorporate sustainability, as it simply broadens the existing process to include new stakeholders, functions and requirements. Further steps in the methodology are concerned with design of the selected option in increasing levels of detail, followed by the production of the system elements and then a process of increasing integration and testing. As this is not relevant to the methodology presented in the following case study, it will not be discussed further here.

Applying sustainability as a design criterion in infrastructure projects faces some obstacles, but these obstacles build a powerful case for employing systems engineering; with its top-down, structured approach to the design process, with a holistic performance and risk assessment at every step, it offers a cost-effective framework in which to consider the introduction of new technologies and the greatest assurance of successful outcomes. Typically, design engineering for infrastructure projects is technologically conservative, since failure of a design has implications for human lives, and as prototyping is most often not an option, mature technologies with predictable performance are generally preferred.

Infrastructure systems are also generally not manufactured, but rather assembled on a construction site. There can be only fragmented ‘factory acceptance testing’, and testing only takes place when the system is completed (such as for a bridge). Contractual divisions also separate the designer and constructor, thereby favouring technological conservatism.

Incorporating sustainability into systems engineering methodology as a design aspect along with constructability, operability, etc, offers other potential benefits in infrastructure projects, since these projects can extend over 50 or 100 years. This warrants life cycle analysis, and also explicit and traced requirements for the system, including up-front consideration of the impact of changes in system performance, dependencies or operating environment.

Incorporating sustainability into infrastructure design through the methodology of systems engineering challenges the current paradigm of impact mitigation, as it forces the re-examination of the fundamental rationale for and functionality of a system, rather than simply minimising the impact of the system to an agreed level. This shift in paradigm leads engineering designers to consider the indirect impact of their project through the resources expended in the construction, maintenance, operation, and decommissioning of systems and facilities, and also to take advantage of opportunities potentially ignored in impact mitigation, such as use of waste as an input to another process.

4. CASE STUDY – Woodman Point wastewater treatment plant odour control upgrade

4.1. Background

The Water Corporation’s Woodman Point Wastewater Treatment Plant (Woodman Point WWTP) is the largest wastewater treatment plant in Western Australia, serving a population of 600,000 people. The plant currently treats 120 ML/day of wastewater and has a rated hydraulic capacity of 160 ML/day, with plant capacity forecast to be reached by 2015. The treatment demand is projected to double by 2045, which will require a plant expansion to handle 240 ML/day. A capacity of 320 ML/day is expected at full development.

The Woodman Point WWTP was developed in 1966 as a primary treatment facility. At that time, residential areas were distant from the plant and the surrounding land uses were rural, public reserves, and industrial. As development continued, the plant was upgraded and expanded several times. In 2000-2002, the plant was upgraded to provide full secondary treatment and sludge treatment with anaerobic digestion and energy recovery. The upgrade also included covering the screens, grit tanks and primary treatment tanks, with the odorous air extracted from beneath the covers and treated in two chemical odour scrubbers.

The odour buffer zone around the treatment plant property is under increasing pressure due to increasing residential development, extending south from existing suburbs northeast of Woodman Point WWTP. There is also significant pressure for further residential development east of Lake Coogee, including an area within the current odour buffer zone. Odour emissions are a problem due to consistent warm temperatures in Perth, combined with an expansive, slow moving sewerage network that brings wastewater to the plant.

In 2003, comprehensive odour modelling predicted that elevated odour levels would occur beyond the existing buffer, although few odour complaints had been received. A subsequent telephone survey of residents close to the plant found that the majority were annoyed by the odour. Complaints have increased significantly since the survey. The environmental regulator directed that odour emissions be reduced by 50% by the end of 2008, with a gradual further reduction in subsequent years. Ultimately, an odour level of 5 odour units (OU) at the buffer zone perimeter will be targeted in a staged approach. This has resulted in an ongoing program of works aimed at reducing odour emissions from the WWTP.

4.2. Odour control system conceptual design

In response to the 50% odour emission reduction mandate from the state's environmental regulator and a general need for upgrades to its assets, Water Corporation formed the W2W Alliance (W2WA) in 2006 with engineering and construction firms Black & Veatch, Thiess, and SKM. The Alliance was formed to deliver a program of upgrades to the State's three metropolitan WWTPs at Beenyup, Subiaco and Woodman Point over a 5 year period. Given the extent and complexity of odour control works that are required, the odour control improvement program was divided into three stages, as summarised in Table 1.

In the initial concept design in 2005, a wide range of odour control technologies were considered, but only two were selected: Two stages of chemical scrubbing and biotrickling filters followed by chemical scrubbers.

Chemical scrubbers were Water Corporation's preferred technology for odour control, both at the Woodman Point WWTP and other major treatment plants. Chemical scrubbers are effective and reliable, and operations staff are familiar with their service and maintenance. However, under high H_2S loads, chemical scrubbers consume more chemicals and become expensive to operate. Biotrickling filters treating high H_2S have a a comparatively lower operating cost. Therefore the Preliminary Design Report (PDR) proposed the use of biotrickling filter technology to remove the bulk of the odour load, followed by chemical scrubbers as a 'polishing' step.

After revision of capital budgets by the client, it was clear that the available capital budgets could not accomodate the full scope of works outlined in the PDR for Stage 1 (Table 2).

This provoked an investigation in 2006 into possible deferrals and alternative stagings, the results of which were summarised in a report entitled "Report on Options for Capital Deferral for Woodman Point WWTP". This report recommended deferring the construction of the biotrickling filters to Stage 2 and employing more chemical scrubbers to treat the odour loads, at the expense of higher operating costs. The biotrickling filters would then be constructed in Stage 2.

When the Alliance odour control design started in 2007, the recommendations were evaluated and concerns arose over the applicability of the recommended plan. A number of key assumptions had changed, and the proposed revised staging was deemed not cost-effective.

A new investigation was then launched to re-evaluate the staging and develop an alternative plan that would improve operability and maximises overall cost effectiveness. The investigation was called "Development of new odour control alternative for capital deferral at Woodman Point".

Table 1 Overview of odour control works and target odour emission rate

Project targets	Scope of works
Stage 1 • Completion date 2008 • Plant inflow at completion 125 ML/day • Baseline odour emissions 290,000 OU/s • Target 50% odour reduction: 145,000 OU/s allowable emission rate	**Improvements to existing odour control system** • Improve odour containment (i.e. upgrade covers, seals etc) • Increase air extraction rates from contained units • Upgrade duct work to handle increased air flows **New works** • Cover and extract air from the anoxic zones of secondary treatment sequencing batch reactors (SBR) • Install ferric chloride dosing in sludge treatment area to reduce H_2S emissions • Install new high-temperature waste gas flares to reduce odour emissions from biogas flaring • Decommission existing chemical scrubbers • Construct new odour control facility to cope with higher air flows and increased loads
Stage 2 • Completion date 2012 • Plant inflow at completion 140 ML/d • Target odour emission rate 135,000 OU/s	• Improve effectiveness of odour control at plant inlet and primary works by increasing the air extraction rates under the covers
Stage 3 • Completion date 2015 • Plant inflow at completion 145 ML/d • Target odour emission rate 75,000 OU/s	• Provide covers and air extraction on new and existing secondary treatment reactors

Table 2 Summary of odour control capital cost estimates versus target cost

	PDR estimate	Target cost
Stage 1 (2008)	$51.7 M	$44 M
Stage 2 (2012)	$6.3 M	$15.5 M
Total	$58.0	$59.5

As part of the investigation, an extensive sustainability assessment of the two design options was conducted to obtain an understanding of the broader context with respect to odour control, and to assess the social and environmental impacts of the options.

4.3. Sustainability Assessment

4.3.1. W2W Alliance sustainability framework

The Water Corporation has a sustainability strategy that strives to deliver social, environmental and economic benefits to Western Australians throughout its infrastructure and services. During formation of the Alliance in 2006, the Water Corporation stated that the Alliance should align with the Corporation's sustainability principles and embed sustainability into core business practice. The principles define three levels of sustainability effectiveness, defined as (from lowest to highest): *Prevent*, *Sustain* and *Enhance* across the three different aspects of social, environmental and economic sustainability. The Alliance was required to translate these high level principles into tangible objectives for its infrastructure projects.

4.3.2. W2WA Sustainability Goals

At its inception, the Alliance developed a set of sustainability goals, in order to provide an over-arching set of practical principles to guide its infrastructure projects.

In accordance with systems engineering methodology, the first step was to consult stakeholders to understand their key drivers and to work together to develop an understanding of what sustainability means in the context of wastewater treatment assets. To achieve this, a workshop was held in which representatives from different areas of the client's business including design, operations, maintenance, asset management, wastewater planning and capital investment, were invited to participate, together with key Alliance staff. The purpose of the workshop was to establish tangible short-term target areas for all Alliance projects across the three metropolitan WWTPs.

The workshop was facilitated by a sustainability practitioner who led the participants through a multi-staged process to finally develop and agree upon sustainability goals. The process was lengthy due to differing opinions on the interpretation of sustainability and its relation to wastewater assets. However, following discussion the group unanimously agreed to specific goals, sorted into target areas, as shown in Table 3.

The goals presented in Table 3 provided a framework for all projects and helped to guide Alliance projects towards sustainable outcomes. It provides a logical structure to assess project options against sustainability criteria tailored to wastewater treatment plants.

Table 3 W2WA five year sustainability goals

Target area	**Goals**
Reduce environmental footprint	Efficient land footprint Reduce chemical use and potable water use Improve effluent quality discharged to ocean Use less, waste less Reduce greenhouse gas emissions
Relevant to future needs	Adaptable to future water re-use requirements Provide robust secondary treatment process for future tertiary treatment processes (re-use)
Operate to maximum efficiency	Improve plant stability and efficiency Ensure operator expertise to optimise plant efficiency
Maximise beneficial outcomes for the community and reputation	Aesthetics, visual amenity improved Minimal impact on the community from odour, noise Deliver and 'walk the talk'

4.3.3. Odour control upgrade sustainability assessment

A specific sustainability assessment was conducted as part of the investigation "Development of new odour control alternative for capital deferral at Woodman Point". The assessment's objective was to determine the difference between the chemical scrubber technology and the biotrickling filter technology within a broader context that aligned with the Alliance's sustainability goals, to provide additional input into the investigation.

The sustainability assessment was conducted through a series of workshops involving the design team lead engineers, the project team, and engineering management from both the Alliance and the client, as well as key stakeholders from operations and maintenance. The process was divided into several steps to produce a semi qualitative assessment:

1) Determine the key sustainability criteria for the odour project;
2) Rate both biotrickling filters and chemical scrubbers against each criterion using a 7-point scale;
3) Determine which criteria are primary drivers, and which are secondary consequences that require management to mitigate impacts.

The assessment was underpinned by the technical work completed by the project team, which formed a rigorous basis for the assessment.

Step 1 – Key Sustainability Criteria

Key criteria were established in consultation with designers and operations and maintenance staff, from which sixteen criteria relevant to the odour control project were identified.

Step 2 – Rating of options against criteria

Ratings were derived from the 7 point scale shown in Table 4, which were aligned with the key objectives for the Alliance. The scale reflects that achieving sustainable outcomes is a goal to be worked toward over the long term and that short term project upgrades may be required to address immediate plant capacity issues. Rankings were discussed and agreed upon within the group of design, operations and maintenance staff.

Table 4 Ranking scale for assessment of technology option

Ranking	Description
4	Progress toward five year sustainability goals
3	Meets scope with moderate sustainability outcomes (supports five year goals)
2	Meets scope plus minor sustainability outcomes
1	Meets current scope of work
-1	Minor negative outcomes
-2	Moderate negative outcomes
-3	Major negative outcomes

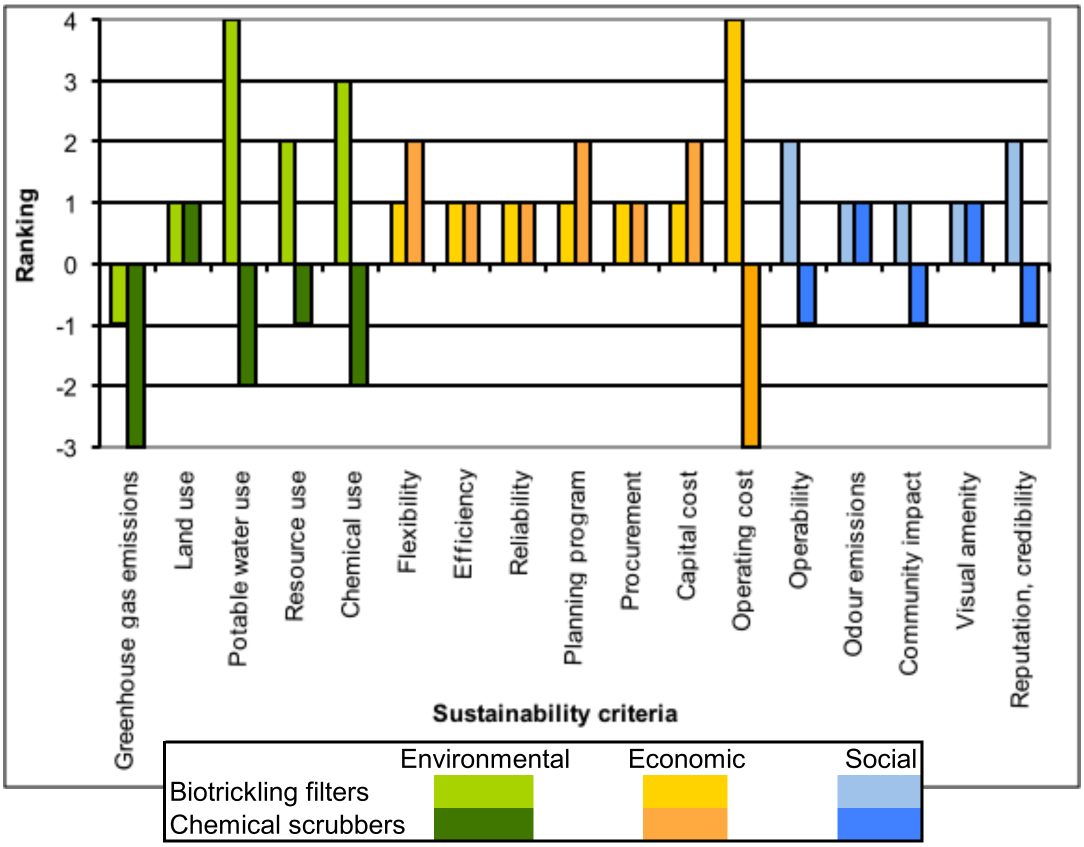
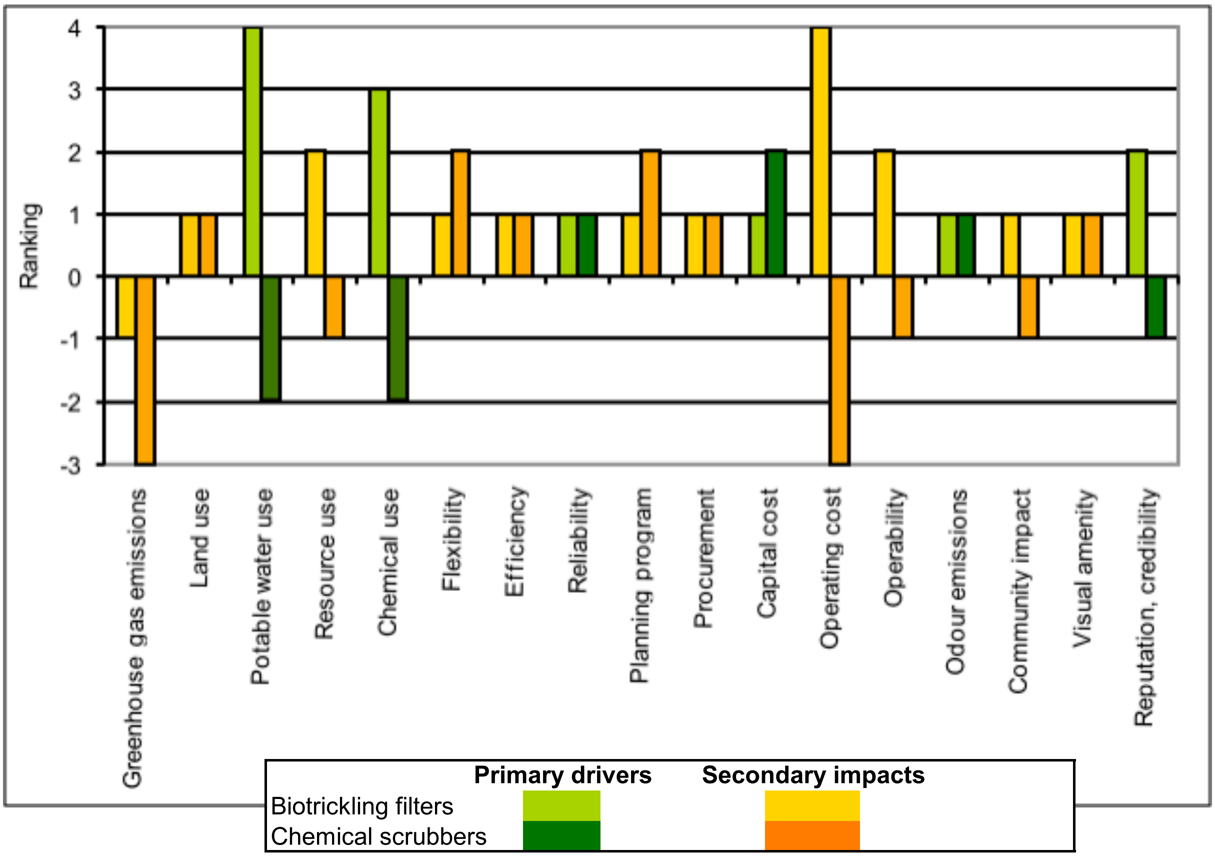


Figure 2 Sustainability ranking by environment, social and economic categories

The outcomes of the ranking are shown in Figure 2, classified into environmental, economic and social categories. The criteria ranking showed that biotrickling filters performed better across most of the sustainability criteria, particularly environmental and social criteria.

Chemical scrubbers performed better with respect to capital cost, program planning and flexibility, but significantly worse for operating costs, potable water use and chemical use. Chemical scrubbers consume large amounts of water; up to 1 million litres in drinking water per day. They require high water quality, since any contaminants could interfere in the chemical scrubbing process. Biotrickling filters, in contrast, can use reclaimed effluent from the wastewater treatment process, which eliminates the use of potable water for odour control. Biotrickling filters perform odour control by relying on the action of microorganisms to oxidise odorous compounds (instead of chemicals), these bacteria require nutrients to grow, which are supplied in the reclaimed effluent. Biotrickling filters therefore eliminate the need for chemical addition, except as a minor ‘polishing’ step, since the biotrickling filters largely eliminate hydrogen sulfide.

The assessment highlighted the traditional appeal of chemical scrubbers, since the capital expenditure is lower in comparison to biotrickling filters. However, when environmental, social and holistic economic aspects are considered, the chemical scrubbers appear less favourable. Prior to this assessment, the two different technologies had been compared on a capital and operating cost basis only. When considering the whole system and its associated indicators and stakeholders, rather than a single economic indicator for decision making, the biotrickling filters performed better.



Step 3 – Primary drivers and secondary consequences

The assessment participants identified that of the 16 criteria, not all were of equal weight or importance. Rather than allocate specific numeric weightings, each criterion was identified as either a primary driver (an essential objective or outcome) or a secondary consequence (impacts or effects that need to be managed).

The assessment ratings for the criteria were presented according to these categories, which provided an additional assessment parameter to assist in identifying the preferred option. It enabled a weighting of those key factors that are critical for the project’s success and effectiveness over the long term. The following criteria were considered primary drivers towards achieving the Alliance's sustainability goals and project success: Reduce odour emissions; meet community expectations; produce a reliable system; reduce potable water and chemical use.

Figure 3 Sustainability ranking by primary drivers and secondary impacts

The rankings for each technology are shown in Figure 3, now classified as either a primary driver or secondary impact. When assessed against the six primary drivers, biotrickling filters performed better than the chemical scrubbers against every primary driver, except capital cost.

4.3.4. Impacts of sustainability assessment

As it was determined that the client's budget could not accommodate the full scope of works for Stage 1, the Capital Deferral Report recommended deferral of the biotrickling filters to Stage 2, with the construction of more chemical scrubbers in Stage 1. This recommendation was made prior to the sustainability assessment, and without an understanding of the broader impacts of that decision. The sustainability assessment helped to provide a systemic, broader view of the advantages and disadvantages of the two different odour removal technologies, to assist with Alliance decision making.

The sustainability assessment highlighted that despite capital cost savings in deferring the biotrickling filters to Stage 2, these savings were outweighed by operating cost, potable water use, chemical use, and operability (the chemical scrubbers are complex to operate). The reliance of chemical scrubbers on a steady chemical supply was also identified as a risk which could jeopardise the odour control systems reliability goal, risking community complaints. The sustainability assessment provided a driver to maintain biotrickling filters in Stage 1 and to seek cost savings through other optimisations.

As part of the investigation "Development of new odour control alternative for capital deferral at Woodman Point" by W2WA in 2007, design optimisations were also found in other areas, including the following:

- Use of the biotrickling filters to treat high strength, lower flow odours from the headworks and sludge handling areas, whilst bypassing relatively weaker, but high volumes of odorous air from the secondary treatment area straight to the chemical scrubbers. This was an innovative and cost effective use of technologies that made use of the biotrickling filters' high removal of H_2S and the chemical scrubbers' ability to achieve low concentrations for odorous compounds.
- Minimising the redundancy by reducing standby chemical scrubbing facilities;
- Reducing the risk of failure of the biotrickling filter treatment system;
- Removing the Odorguard system (a chemical scrubbing system which had been problematic during operation at other sites);
- Reducing design contaminant loads following more extensive sampling and monitoring;
- Reducing the complexity of the system.

The sustainability assessment was a key driver for ensuring a more holistic design optimisation was sought, rather than simply deferring the biotrickling filters to stage 2. The biotrickling filters are now under commissioning, and preliminary operational results are expected soon.

5. CONCLUSIONS

Sustainability is a growing concern for the community, resulting in pressures on government, business and ultimately the engineering of projects to meet community needs. Sustainability increases the complexity of engineering projects, yet this complexity can be handled by an existing methodology – the systems engineering methodology. Systems engineering provides a structured, 'top-down' approach that ensures that all the stakeholder requirements and their complex interdependencies are correctly identified and then reflected throughout the detailed development of the project. Infrastructure projects are well suited for the application of systems engineering, in which sustainability is incorporated as a design aspect.

The W2W Alliance upgrade of odour control facilities at Woodman Point wastewater treatment plant (WWTP) in Western Australia is an example in which systems level sustainability assessment of two technologies was conducted, in order to guide decision making with respect to the design selection. The upgrade to biotrickling filters has resulted in a step-change in the WWTP's environmental footprint, since a biotrickling filter system consumes up to 95% less chemicals and can use reclaimed effluent (i.e. treated wastewater) in lieu of potable water, yet achieves the comparable odour removal. Community pressures are expected to soften given the predicted high levels of odour removal for the system.

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BIOGRAPHY

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Erik Aslaksen is a Senior Consultant at Sinclair Knight Merz and has worked at the firm for 20 years. His main focus has been on systems engineering and the management of

multidisciplinary projects. His skills include requirements management, system architecting, and performance modelling. Erik has experience in the modelling and optimisation of complex systems and processes, extensive experience in both line and project management of research, engineering, and production. Within electronic engineering, he has many years of experience in communications, power electronics and process control. He has worked as a design manager, project manager, independent verifier, and has been the project manager for multi-million dollar EPCM projects, such as the North Parkes E26 Mine project.

Dr Katie Third
Katie is a wastewater consultant experienced in development, design, operation and optimisation of industrial and domestic wastewater and sludge treatment systems, with specific expertise in biological nitrogen removal and modelling. Katie also has significant experience in implementation of sustainability into planning, conceptual design and operating strategies for water and wastewater treatment plants, and the translation of high level sustainability principles into tangible tools and outcomes for water infrastructure projects. Katie has worked at SKM for almost three years and has worked previously in the Netherlands, Dutch Caribbean and the USA. She is currently working as part of the W2W Alliance, an alliance between Black & Veatch, Thiess, SKM and Water Corporation, to upgrade Beenyup, Subiaco and Woodman Point WWTPs.

Andrew Shaw
Andrew is a Process Specialist with Black and Veatch in their Water Technology Group with over 15 years experience carrying out process design and computer modeling for major wastewater treatment facilities. In 2006, he was seconded to the W2W Alliance program of works in Perth, Australia where he helped to develop a comprehensive greenhouse gas model for the metropolitan wastewater treatment facilities. He also helped to carry out several sustainability assessments for various process upgrades. He is part of a team of specialists looking at carbon footprinting as part of Black and Veatch's Drive for Value on Sustainability.

Barnaby Smeaton
Barnaby is a graduate mechanical engineer with three years work experience at SKM. He has previously worked in the vibrations, noise and structural modelling and testing team in SKM, but is now working in general mechanical engineering project management and design work. He has recently begun working in a systems engineering capacity for clients, and worked with the AAO on a concept design for a major international scientific instrument, the Gemini-sponsored Wide Field Multi-Object Spectrograph. Barnaby is working closely with Erik in building a Systems Engineering Community of Practice in SKM. Barnaby can be contacted at bsmeaton@skm.com.au