Sustainability indicators for wastewater reuse systems and their application to two small systems in rural Victoria, Australia

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Abstract: Currently there is no tool to assess the sustainability performance of reuse systems in Australia. This research fulfills that gap by developing a set of sustainability indicators (SIs). A unique methodology was developed based on understanding of the reuse systems, reviewing and examining the issues related to reuse, and Australian policy and guidelines in terms of sustainability. It was established that a sustainable reuse system should be based beyond the triple bottom line approach, and involve consumers in decision making, address institutional issues, and focus on the outcomes rather than the output, with a system approach. Twenty seven SIs were identified under five categories: environmental, technical, social, economical, and institutional. The case studies demonstrated the application of the SIs in sustainability assessment of two reuse systems: (1) tree plantation and (2) lake discharge for augmenting environmental flow. The evaluation was done based on multi criteria decision assessment.

Key words: sustainability, indicators, SIs, sustainability assessment, multi criteria decision assessment, wastewater reuse.

Résumé : Il n'existe présentement aucun outil pour évaluer le rendement durable des systèmes de réutilisation de l'eau en Australie. La présente recherche comble ce manque en développant un ensemble d'indicateurs de durabilité. Une méthode unique a été développée basée sur la compréhension des systèmes de réutilisation de l'eau, revoyant et examinant les questions ayant trait à la réutilisation ainsi que la politique et les lignes directrices australiennes en termes de durabilité. Il a été déterminé qu'un système durable de réutilisation de l'eau devrait aller au-delà de l'approche du triple résultat net, impliquer les clients dans la prise de décision, aborder les questions institutionnelles et porter une attention spéciale aux résultats plutôt qu'au rendement, tout cela avec une approche système. Vingt-sept ensembles d'indicateurs ont été identifiés dans cinq catégories: environnement, technique, social, économique et institutionnel. Les études de cas ont démontré l'applicabilité des ensembles d'indicateurs dans l'évaluation de la durabilité de deux systèmes de réutilisation de l'eau, (1) une plantation d'arbres et (2) un déversoir de lac, pour augmenter l'écoulement dans l'environnement. L'évaluation a été réalisée en se basant sur une évaluation de décisions multicritères.

Mots-clés : durabilité, indicateurs, ensembles d'indicateurs, évaluation de la durabilité, évaluation de décisions multicritères, réutilisation des eaux usées.

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1. Introduction

With increasing pressures on water resources, the importance of "total water management (TWM)" is recognized by water agencies around the world. Reuse of treated wastewater is a major component of TWM. Australia is one of the driest continents on earth. Water reuse is crucial for the efficient use of water resources to meet future human and environmental water needs in Australia. Although wastewater reuse is in practice for decades and substantial progress has been made over the years in terms of reuse applications, the long-term sustainability of reusing wastewater for beneficial use is not known. While environmental impact assessment is carried out in the planning phase, it is only predictive of the possible impacts of the system on the environment. Examining the sustainability of reuse systems is essential for rural Victoria, where 85% of the reuse is land application (DNRE 2002), and impacts are observed in terms of salinity of groundwater and soil (Godfree and Godfrey 2008; US EPA 2004). Wastewater contains higher concentration of salts such as sodium, chlorides, boron (Godfree and Godfrey 2008). There can be a range of constraints on land capability; salinity, sodicity (excess Na ions, compared to K ions), N (surface and groundwater contamination) and so on. Salinity is one of the major impacts, and considered in risk assessment of wastewater discharges to waterways (EPA Victoria 2009). According to FAO (2002) salinization of soil is the most important negative environmental consequence of agricultural wastewater reuse, affecting about 20–30 million ha of irrigated land.

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Water authorities in Victoria now need to undertake sustainability reporting as mandated by the State Environmental Protection Policy (SEPP). Therefore having a sustainability assessment tool is essential. The Victorian Auditor General's office, whose primary task is to audit the performance of public sector organizations in state and local government level, identifies the broader applicability of sustainability assessment in improving the performance of organizations. The Auditor General's report emphasizes the need of a holistic approach of measuring the sustainability by incorporating not only environmental aspects but also social and economic aspects in an integrated manner (Victorian Auditor General's Office 2004). Sustainability indicators are one such tool because it takes into account multiple aspects of sustainability and their interrelationship (Bell and Morse 1999; Bossel 1999).

There are studies to identify which treatment technology among mechanical, lagoons, and land treatment is more sustainable (Muga and Mehelcic 2008). Similarly many studies are carried out to assess the sustainability of wastewater treatment systems, to name a few — Lundin et al. (1999); Hellström et al. (2000); Balkema et al. (2002); Murray et al. (2009). Balkema et al. (2002) summarized the indicators used to assess sustainability of wastewater treatment systems, and proposed multi objective optimization method to find out the trade- offs between the indicators. Murray et al. (2009) developed a burden vs. capacity sustainability assessment framework (B2C SA) and identified 23 indicators for three life cycle phases — production, treatment, and end use of wastewater infrastructure. There are some studies pointing out the issues in reuse (Anderson 1995; MacCormic 1995; Hermanowicz et al. 2001; MacDonald and Dyack 2004; Asano and Cotruvo 2004) and probably only a few on sustainability indicators for the wastewater reuse such as Kennedy and Tsuchihashi (2005). Kennedy and Tsuchihashi (2005) proposed a range of "sample indicators" for sustainability of reuse under seven performance categories: water quantity, water quality, environmental quality, resource utilization, economics, socio-cultural, and functional and (or) technical. However, the evaluation of sustainability of wastewater reuse systems as a whole has not been attempted in a comprehensive way yet in the sense that usually sustainability is investigated based on three aspects — environmental, economic, and social where a triple bottom line (TBL) approach has been used. As the Victorian Auditor General's Office (2004) has pointed out, the TBL is a reductionist method that effectively separates the three aspects and analyzes them as though they were not related. This study did the assessment based on five categories: environmental, technical, social, economical, and institutional, and included indicators on involving consumers in decision making, addressing institutional issues, and focusing on the integrated outcomes rather than the individual outputs, with a system approach. Evaluating current reuse systems for sustainability is important to make sure the systems do not impart any negative impacts over the course of its operation and if it does, then suitable measures can be taken to address the issue on time. This paper presents the development of a set of sustainability indicators (SIs) and its application in the sustainability assessment of wastewater reuse systems in rural Victoria. The sustainability assessment of two reuse systems was done based on multi criteria decision assessment. The following two paragraphs examine the definition of reuse versus recycling, and issues in reuse. Section 2 reports on the methodology, section 3 describes the development of indicators, section 4 explains the implementation of the indicators to case studies. The sustainability evaluation is presented in section 5, discussion of findings is given in section 6, and section 7 summarizes the conclusion.

1.1. Reuse vs. recycling

In the literature reuse and recycling are used interchangeably. Reuse is broadly defined as "*the utilisation of water for some further beneficial purpose*" (EPA Victoria 2003). Asano (1996) defines reuse as "*the utilization of reclaimed water for a variety of beneficial use*" whereas wastewater recycling is defined as "*only one use or user and the effluent from the user is captured and redirected back into the use scheme*". Reclaimed water is the treated wastewater that is appropriate for reuse. Considering municipal water supply and wastewater system as a user, reuse refers to any kind of use after the wastewater leaves the boundary of the sewerage system. Reuse was thus defined as any other beneficial use such as irrigation, environmental purposes or groundwater recharge. Recycling necessarily means the application of wastewater back into the system, either in the form of a potable or non-potable source that can replace the demand for water resource within the system. Thus recycling can be considered as a subset of reuse in general. Figure 1 clarifies the concept.

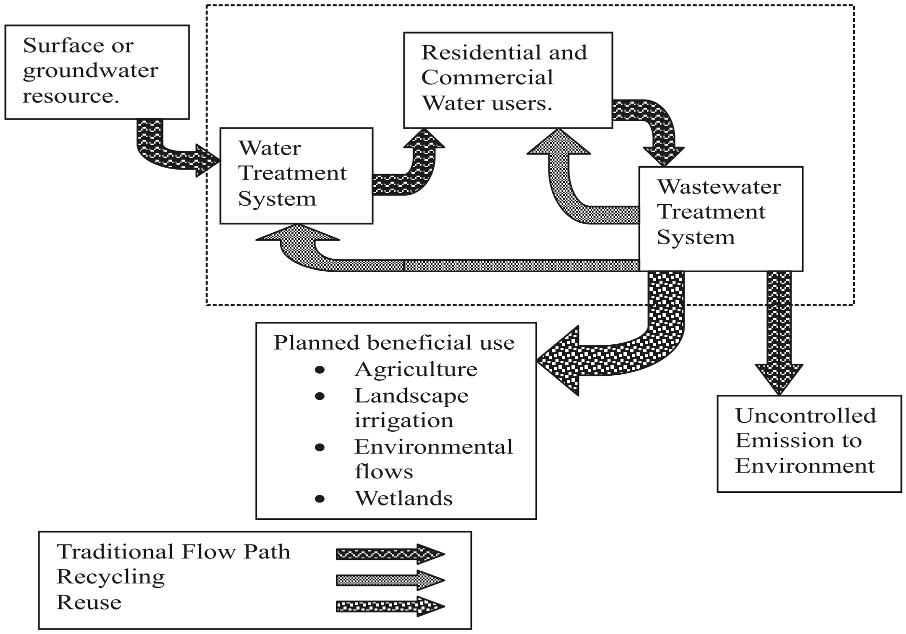
It should be noted that in some cases wastewater is released to streams by deliberate process to encourage extraction by downstream users.

1.2. Issues in reuse

Public health, environmental sustainability, quality of food products, social acceptance, treatment technology capability and reliability, monitoring systems, economics of recycling, and availability of expertise are some of the long-term issues associated with reuse (Dillon 2000) that can create unsustainable conditions in the future. Challenges exist in the reuse of wastewater in the form of health risks, public acceptance, impacts on the natural environment, economic limitations, legal and regulatory obligations, and institutional challenges (Anderson 1995; Hermanowicz et al. 2001; MacCormic 1995). In the Australian context MacDonald and Dyack (2004) have noted seven institutional impediments to water reuse: consumer perception, economics of the reuse market, property rights, governance, health and safety, environmental protection guidelines, and research and development. Furthermore, the *Victoria*'*s Water Recycling Action Plan 2002* had identified and addressed the barriers of water reuse as unclear accountability, lack of commercially attractive returns, and complex environmental and health regulations. While the US EPA guidelines address technical, quality, public health, legal, and institutional issues (US EPA 2004), Australian Guidelines for Water Recycling (Natural Resource Management Ministerial Council 2008) focuses on health and environmental risks.

Climate change can also impact reuse systems. Climate change is a broad issue where increased frequency or severity of algal blooms, floods, droughts, bushfires could result from the impacts of climate change. The several algal blooms in

Fig. 1. Differentiation between reuse and recycling.



the 1990s and great millennium drought brought focus on the value of reclaimed water, so reuse was encouraged by the Council of Australian Governments (CoAG), and reuse targets were set (Apostolidis et al. 2011). In this sense algal blooms and droughts led to increased reuse applications. Energy used in reuse can increase the green house gas emissions. The wastewater treatment contributes 58% of total GHG emissions coming from the urban water and wastewater sector in Victoria (ESC 2009), however the contribution of the reuse component is not known. How climate change affects the reuse system is not examined in detail in this study, and can be a separate subject of research. The primary focus in this paper is to provide an evaluation tool that can be implemented in assessing sustainability of reuse systems in rural Victoria, and is thus based in the present. Fully incorporating issues of climate change is best dealt with as part of the predictive modelling and design tasks of water reuse systems, which is beyond the scope of this paper.

2. Methodology

To carry forward the study, reuse options were studied, stakeholders were identified, legislation and regulatory requirements were understood, and impediments to reuse were studied. These findings formed the basis for selecting the methodology. The research was conducted implementing the pathways shown in Fig. 2.

Review of sustainability related journal papers, the Brundtland report (Victorian Auditor General's Office 1987), and Australia's sustainability policy as reflected for example in Environment Australia (2002, 2003), DSE (2003), and EPA Victoria (2002) was done to understand the concept of sustainability in terms of wastewater reuse system. A site visit to the Melbourne Water's Western Treatment Plant (WTP) that utilizes land application for the treatment of wastewater and reuses a component of the wastewater for irrigation was conducted to help understand the issues for a very large treatment system. Although the WTP used land treatment for around 100 years and is often referred to as a long-term sustainable solution for wastewater treatment, this has proven not to be the case. A combination of nutrient emissions to Port Philip Bay, odour emissions to the surrounding residential areas, and the accumulation of heavy metals in sludge and some land treatment areas have forced significant changes to the system where now most of the water is treated using a combination of anerarobic and aerobic digestion in conjunction with biological nitrogen removal. Two rural reuse facilities were visited to understand smaller systems from an operational as well as design point of view. These two sites were used as case studies rather than the more complex and clearly unsustainable example of the WTP. Formal and informal meetings were held and questions were asked to related people from the rural water authority to gain an understanding of the system (Coutt 2004[1]).

Existing sustainability indicators were reviewed. Australian environmental indicators were studied, SEPP was reviewed and analysed in context of reuse system. The limitations and impediments to the reuse of wastewater was studied and understood which helped develop the SIs.

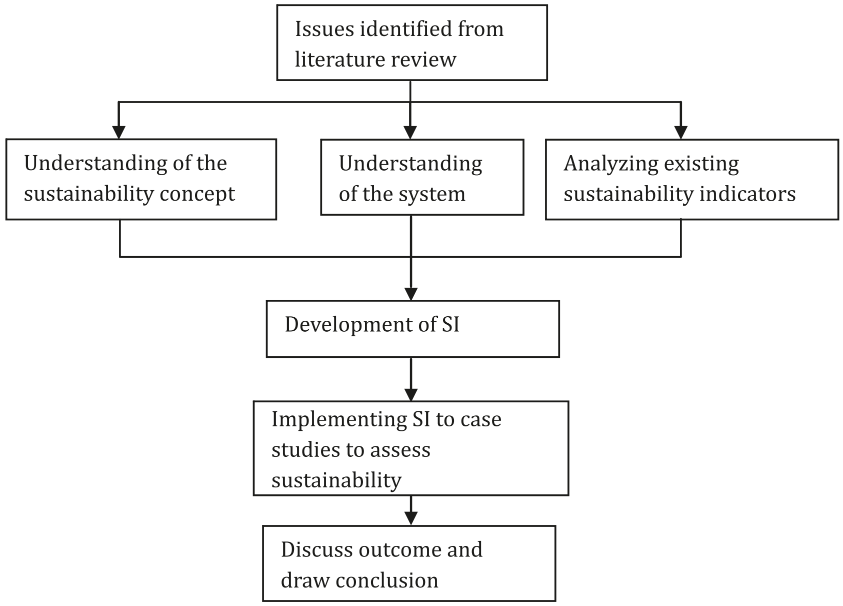
The development of the SIs and its application in the sustainability assessment of reuse systems in two case studies are described in following sections.

3. Sustainability indicators development

Sustainability indicators quantify sustainability and provide guidelines to assess the current situation against indicators (Bell and Morse 1999; Lundin et al. 1999; Hellström et al. 2000; Balkema et al. 2002; Kennedy and Tsuchihashi 2005; Muga and Mehelcic 2008; Murray et al. 2009). Indicators are a tool to measure criteria, which should be measurable (Hellström et al. 2000) and they are "parameter chosen to re-

[1]S. Coutt. 2004. Environmental Officer, Grampians Wimmerra Mallee Water. Personal Communication.

Fig. 2. Research pathways.



flect sustainability" (Lundin et al. 1999). However, quantifiable criteria are not the only indicators of sustainability. Social factors are very important indicators to assess sustainability of any system despite the fact that they are difficult to quantify. There must be a reference point for sustainability and trends of system performance should be interpreted over a period of time (Bell and Morse 1999). There must also be some threshold level with respect to which the sustainability of the system should be gauged. Even if a system is performing well with respect to a reference point, it might be below the threshold level, thus is unsustainable. Alternatively, if a system performance is above the threshold level in a given period of time, but the progress with respect to the reference point is downward, the system should be considered unsustainable. Therefore, the sustainability of a system should be measured with respect to a reference point, rates of change from the reference point, and a threshold level.

Criteria for assessing sustainability vary from system to system depending on variability of objective of the system, physical location, climatic conditions, and social structure. Therefore it was important to develop a set of indicators considering all the environmental, economic, social, institutional and regulatory impediments and arrangements that can suit rural Victorian reuse systems. Each indicator was selected on the basis of issues identified after reviewing relevant literature and the government's approach to interpreting sustainability in practice. Criteria noted in Table 1 were used to select the indicators.

On the basis of literature reviewed and theoretical analysis, some indicators have been identified to address the issues of existing as well as future wastewater reuse systems. The threshold values are assigned for quantifiable indicators where as emphasis on long-term monitoring is given for others.

3.1. Environmental indicators

The groundwater, surface water, natural habitat and soil are considered key environmental indicators.

3.1.1. Groundwater

Pathogens, total dissolved solids, heavy metal toxicants, organic substances and amount of salinity present in the aquifer after groundwater recharge or indirect percolation of wastewater into the aquifer are considered as quality indicators for groundwater. The EPA Australia guidelines for reclaimed water for secondary treatment have been used as the threshold value. In case of percolation, background concentration was considered as the threshold. The rise or fall in salinity of groundwater up to 10%, was taken as the threshold value; however some researchers argue that most providers cannot meet this criterion and need an exemption (Brissaud 2004). In such circumstances, it may be better to allow an increase in the threshold value after extensive monitoring. Rise or fall in the natural water table is considered as a quantity indicator of reuse into the given aquifer. It is not possible to put a limiting value on rise or fall in the water table, as it depends on depth, existing withdrawal and recharge rate and other hydrogeological factors. Therefore, it is important to monitor the water table, identify the risks of the changing level, and develop a management plan to deal with it.

3.1.2. Surface water

Overflow from a reuse system and enhancement of environmental flow are considered as surface water indicators. One incident of un-seasonal flow due to overflow in a year caused by the reuse system is considered the threshold. Reuse can enhance or reduce the environmental flow, depending upon the type of reuse. Generally, allowance for environmental flow is allocated on the basis of headline sustainability indicators for water, which require leaving or redirecting a certain percentage of flow into the waterway. To satisfy the environmental flow concept, the reuse system should discharge into the waterway, wherever possible, to help achieve this target. In some cases a requirement for flow variability or even certain periods of no flow may need to be considered. However, this is contrary to the current SEPP, which encourages the application of wastewater to

Table 1. Indicator selection criteria.

Indicator category	Indicator selection criteria
Environmental	Possibility for reuse, resource conservation, environmental risk reduction
Technical	Practicality, availability, reliability, quality of reclaimed water
Economic	Benefit–cost ratio, ongoing benefit
Social	Health, public acceptance, aesthetics
Institutional	Stakeholder involvement, capacity building

land as an initial consideration based on concern that increased nutrients from reclaimed water may lead to algal blooms. It can be argued that in many cases reclaimed water may have or can be made of equal or better quality than natural water and can be used for restoring environmental flow. Therefore, provision for discharging reclaimed water, wherever applicable, back into the waterway, is considered as an important indicator. However, such discharge should be examined on a case-by-case basis.

3.1.3. Habitat

Biodiversity and disease vectors are considered habitat indicators. The reuse system should not disturb the natural habitat of flora and fauna due to overflows, increased temperature or insufficient flow into the waterway. Rather the reuse should enhance the biodiversity, wherever possible. For example, Lake Borrie, one of the wetlands at the Western Treatment Plant in Melbourne, receives a dedicated flow of class C recycled water to protect biodiversity values. The Western Treatment Plant is listed as a Ramsar wetland of international importance.

In contrast, reusing wastewater for wetlands or other ornamental ponds where flow velocity is very low or water is stagnant for a long period of time is considered a risk to become a habitat for disease vectors especially when global temperature is rising due to climatic variations. Risk assessment of such vulnerable sites should be done and specific management plans for vector control should be in place.

3.1.4. Soil

The rise or fall in the level of salinity, boron concentration, pathogen, and heavy metal toxicants are important indicators. A percentage change to the original level may be considered rather than a limiting value because the use of reclaimed water is not the only factor that influences these parameters in any catchment. Crop type, depth of root zone, initial characteristics of the soil and climatic conditions are decisive factors. Furthermore, the rate of change in the above mentioned parameters should be such that it does not cross the maximum tolerable concentration in the catchment. There should also be a management plan in place to deal with increasing concentrations. Moreover, there should also be a vision to deal with the problem when the soil is unable to sustain the existing land use. This may be done by changing land use or accepting a change to property value and decreased production level. This requires considering the economic and social dynamics of the catchment at that time and extensive research in this area rather than allocating any single number value as an indicator.

3.1.5. Biosolid use

The energy and nutrient value of biosolid use should be considered. In cases where it is not possible to use the entire biosolid produced, it can be economical to stock pile for an extended period of time and then transport it to some other place for use. Again the importance of having a future planning and management plan is essential to deal with the biosolids.

The quality aspects of biosolid reuse should comply with the EPA guidelines for biosolid reuse. Presence of heavy metals in biosolids is a big concern and should be addressed while deciding on the specific reuse option and method for biosolids use. This is not investigated further for this study.

3.2. Technical indicators

Quantity, quality, and energy consumption are considered as technical indicators.

3.2.1. Quantity

The quantity of reclaimed water available for reuse depends on the availability of potable water itself. In Victoria, the average household consumption was 160 kL/household in 2007–2008, a 11.11% reduction compared to the previous year. The consumption was higher in rural Victoria — 176 kL/household compared to 153 kL/household in Metropolitan Melbourne (ESC 2009). Generally all the water consumed in households except that used for drinking, evaporative coolers, and outdoor use such as gardens can be reused. Theoretically all water entering the wastewater system can be reused. However, the quantity of wastewater available at the end is the main determinant of how much water can be reused. All the reusable wastewater may not be collected as some fraction of this water can be recycled at the household level, which is a positive thing and the water utility can encourage such practice. Some wastewater may be lost during the conveyance. System losses in the WWTP, losses from leaky sewers and ponds, and even water leaking into leaky sewers might be more significant technical quantity issues. For the purposes of this research these components are not considered.

Besides potable consumption, the market availability and seasonal variation in demand also determine the quantity of wastewater reused. For example, in metropolitan areas reuse of wastewater and biosolids is governed by the availability of land on the fringes of the city. Similarly, the type of application can greatly affect the quantity. For instance, reuse for golf course irrigation requires a substantial quantity of water. Variation in demand also determines the quantity of reuse of the water. Therefore, the quantity of wastewater reused is a major indicator of sustainability. The higher the percentage of reuse, the more sustainable the system will be.

3.2.2. Quality

The quality of the reclaimed water depends on the type of reuse. If the reuse is for direct potable purpose, the treatment of the wastewater should be of a very high quality. The EPA has different quality guidelines for various classes of water used for varied purposes. The reuse systems must satisfy these guidelines. The level of treatment is therefore an important parameter for gauging sustainability. However, to assign a threshold value in general is not possible hence if the quality of reclaimed water is up to the required standard, it is considered sustainable. The treatment below the required level or above the required level, generally termed as improper use, both are considered unsustainable. The treatment above required level may require a high level of technology, requiring more resources and energy, which in turn can increase the cost and GHG emissions, respectively.

Salinity and pharmaceutical byproducts are a concern in reuse. Salinity is a key issue for irrigation reuse, and is partly under the control of the water company via its trade waste agreements and education and regulation of salt content of detergents. Impacts of pharmaceutical byproducts, personal care products and endocrine disruptive substances are understood to some extent but its impact on direct reuse of water is not understood. These emerging issues have to be observed and addressed by the water company.

3.2.3. Energy

Energy is an important indicator not only from resource optimization perspective but also from climate change perspective, considering the impacts of energy usage from non renewable source and its contribution in increasing green house gases in the atmosphere. The system consuming less energy per ML of reclaimed water produced every year should be considered a more sustainable system provided differentiation is clearly made between initial energy to produce and convey the wastewater and energy recurring in operation, treatment, maintenance, repair and replacement of the reuse system. Again the system variables such as distance of property from the source, difference in elevation between source and service area, and type of source whether it is gravity fed or pumping fed, has a significant effect. Embodied energy in the capital infrastructure should be considered based on the life cycle approach. The possibility of energy recovery from biogas should be considered while calculating the total energy consumed.

Sustainability may also vary according to the type of energy; whether it is produced from a non-renewable or renewable resource and its contribution to the green house gas effect. While the use of energy from renewable resources is generally considered positive, the total energy per ML is still the most important indicator in this space because inefficient use of renewable energy deprives other users access to the renewable energy where it is in short supply. Possible impacts of climate change on the reuse system over the period of time can be monitored and indicators can be added or modified as needed. This could be a separate subject of research.

3.3. Economic indicators

There is a debate about the inclusion of economic indicators to assess sustainability. The authors consider sustainability from a broad point of view, not just from the environmental viewpoint. We contend that economy is a subsystem of the broader social system, which is in turn a subsystem of the environment on which we all rely. One can contrast this to the TBL approach where these three systems are effectively treated as separate entities. If the economy is not sustainable, then this will have negative impacts on the sustainability of the social and environmental systems. Benefit–cost ratio and ongoing benefits are considered as economic indicators. It is argued that the benefit–cost ratio is an indicator that should be assessed on an ongoing basis, rather than as justification for a major decision, which is more typically the case. Because the wastewater treatment plant is part of a wider economy that is continually changing, the benefit–cost ratio will also change. Most wastewater treatment plants in regional Victoria were established when environmental costs were not recognised, the thought of deriving income from water reuse, and the concept of the polluter paying for treatment of waste to an acceptable level were not considered. Without a watching brief on this indicator, rapid changes in factors such as demography can result in systems once considered sustainable quickly becoming unsustainable on this indicator. If this occurs the responsible authorities could react, for example, by reassessing the social benefit to justify economic subsidy from elsewhere in society or changing the technology used to be more appropriate for the current conditions and foreseeable future.

3.3.1. Benefit–cost ratio (BCR)

A full economic analysis of any reuse project considering all externalities is essential to ensure long-term sustainability of the system. However due care should be taken to avoid double counting some items if the true external costs or benefits are considered.

For a reuse system to be sustainable, it should be viewed as a social system hence social BCR is considered as an indicator rather than the financial evaluation which focuses on the benefit of institution involved in operation. A BCR of 1 is considered as a threshold value and the higher the BCR ratio, the better the sustainability level. However, even if the economic BCR is less than one, considering the ongoing, non-monetized social or environmental benefits, the system can still be sustainable if a community decision is made to accept that.

3.3.2. Ongoing benefit

In regional Victoria where many systems have been operating for decades and full economic evaluation might not have been done, ongoing benefits of the reuse system to the broader community should be considered another economic indicator.

For the systems that were not designed on the basis of extensive economic evaluation, it is essential to monitor whether the direct or indirect benefits to the broader community outweighs its operational costs, ignoring its initial capital investment. The equal ongoing benefit to the operating cost is considered as the threshold and the higher the benefit, the more sustainable the system will be. The initial investment can be considered as a *sunk cost*[2] for such systems and can be excluded from the economic evaluation, however, replacement cost of infrastructure should be consid-

[2]Sunk cost is the investment done in the past which is irrelevant to the future investment decisions.

ered. Therefore, it is an important indicator of the success of an existing reuse system.

3.4. Social indicators

Human health, aesthetics, and public satisfaction are considered as social indicators.

3.4.1. Human health

Considering the system boundary from Fig. 1, the reuse of water for various beneficial uses exposes the community to a level of risk in the eating of the food or use of recreational facilities. The number of gastrointestinal disease cases reported should ideally be considered as an indicator. However, since it is so hard to measure disease incidence and attribute a cause, pathogens in the water and risk management systems for workers and the public to protect healthcare can be a better indicator.

Reuse systems may not be the only cause of waterborne illnesses; it may also arise from polluted water supply, improper storage of water or personal hygiene. In such cases, it must be determined that the reuse system is not responsible for such outbreaks. Meanwhile, the health risk underlines the importance of awareness and education about the safe handling of reclaimed water to these target groups.

3.4.2. Aesthetics

One of the main hurdles for reuse is the aesthetic factor. Visual amenity and odour are important aspects. The EPA guidelines suggest the amount of chlorine as an aesthetic parameter in reclaimed water in relation to recycled water, for example to third pipe schemes. The aesthetic is more important in case of direct reuse. Hence, aesthetics of the reclaimed water, the wastewater treatment plant, and the reuse site is considered as a sustainability indicator. However, at the time of extreme drought and flooding aesthetics may be compromised, and special consideration should be made for such circumstances. Application of reuse in ornamental pond and wetlands can add to the aesthetics, and should be considered.

3.4.3. Public satisfaction

Satisfaction of the people using the reclaimed water or indirectly involved in using it is considered as an indicator. To know the degree of consumer's satisfaction, the number of complaints reported to the responsible authority is considered as an indicator and a maximum of 5 complaints/100 customers/year has been selected. The responsible authority could be the one involved in the treatment and distribution, or the EPA, or a related food authority. However, complaints regarding cost of service or administration should not be included. Currently in Victoria central recording of such complaints is not in practice, but it is a useful indicator to manage the systems in the long term.

3.5. Institutional indicators

Upgrading staff skills, community education and awareness programs, and involving the community in decision making are considered major institutional indicators.

3.5.1. Upgrading staff skills

Improving staff's overall capability to cope with changing technology, regulatory arrangements, work environment, and to deal with the public is considered as an important indicator. The engineers should have a 150 h of continuing professional development (CPD) every 3 years (Engineers Australia 2005) and the operators should have relevant training based on nationally accredited Water Industry Training Package (National Training Information Center 2005).

3.5.2. Educational and awareness program

Conducting educational and awareness program about safe and proper reuse and its importance in the supply security increase acceptance of reuse in the community. It should be noted that not only the users but also people involved in production, distribution and management should also be educated about the possible risks and benefits of reuse. The need for such programs to cope with the increasing mobility of the population due to tourism and lifestyle changes increases the importance of this indicator

3.5.3. Community involvement in decision making

Involvement of the community at any stage of the project in any form is regarded as an indicator for sustainability. It may be in the form of consultation prior to formulating projects or direct involvement in operation or management or in some other way.

Table 2 lists all the indicators. As explained in the beginning of section 3, sustainability of a system should be assessed against a threshold level to indicate a minimum acceptable level of performance. Similarly maximum acceptable values are also necessary. Based on prevailing regulations and guidelines, threshold and maximum values are assigned. In cases where assigning such numbers are not possible, having a satisfactory result is considered as threshold. For example, for heavy metal toxicants the threshold depends on the background concentration of the groundwater in a given area or aquifer, and the water quality guidelines values — whichever is less will govern. Therefore, a specific threshold is not possible to assign and a "satisfactory" result is considered as the threshold.

While developing indicators for reuse systems in rural Victoria, monitoring and having a management plan is emphasized and recommended for the following indicators in general: groundwater table, controlling disease vectors, soil quality (salinity, toxicants, nutrients, boron, pathogens presence in top layer), and biosolid use. For individual systems, depending on specific situations further monitoring of indicators can be recommended.

4. Case studies

To 'road test' the set of indicators put forward in section 3, two quite different instances were chosen. These instances were not chosen to prove or disprove the correctness of the indicators, but to test the utility of them and provide a backdrop for the discussion of the indicators within the resources available to this study.

The Donald tree plantation and Willaura lake discharge systems were chosen as case studies to examine the applicability of the SIs and evaluate the sustainability of these systems. Although the Donald system is small, it is representative of the reuse applications in rural Victoria. Water reuse is more common in non metropolitan rural areas away from the coast because of lower rainfall, and increased agricultural reuse

Table 2. Sustainability indicators for wastewater reuse systems in rural Victoria.

Indicator #	Sustainability indicators	Unit	Threshold value	Maximum value
Environmental indicators				
Groundwater				
1	Quality of groundwater recharged (comply with EPA Guidelines or with the background concentration in case of indirect percolation)			
1.1	*E-coli*	cfu/L	0	1
1.2	SS	mg/L	0	30
1.3	BOD	mg/L	0	20
1.4	Heavy metal toxicants e.g., Fe, Pb, Hg, Ni, Cd (should meet the background concentration of the groundwater or drinking water quality guidelines whichever is less)	mg/L	Satisfactory	
1.5	Salinity level	% of original level	0	±10%
2	Quantity of recharged water			
2.1	Monitoring water table and management plan for changed condition	Value per annum	Satisfactory	
Surface water				
3	Flow into the water way			
3.1	Incident of un-seasonal flow into the waterway	Number		
3.2	Restoration of environmental flow	Annual	Satisfactory	
Habitat				
4	Habitat restoration	Annual	Satisfactory	
5	Management plan for controlling disease vectors	Annual	Satisfactory	
Soil				
6	Management plan for dealing with changing soil quality (salinity, toxicants, nutrients, boron concentration, pathogens presence in top layer)	Value per annum	Satisfactory	
Biosolid use				
7	Provision of biosolid use and management plan for excessive biosolid	Annual	Satisfactory	
8	Quality of biosolid (comply with EPA guidelines)	Per L	Satisfactory	
Technical indicators				
Quantity				
9	Quantity of wastewater reused	% of wastewater generated	50	100
Quality				
10	Treatment of wastewater (comply with EPA guidelines for respective beneficial use of water)	Satisfactory		
11	Source reduction (wherever other reuse options are not feasible)	As much as possible	Satisfactory	
12	Energy consumption for reuse component	As minimum as possible	Satisfactory	
Economic indicators				
13	Benefit–cost ratio	Ratio	1	
14	Ongoing benefits (to user and society at large)	Equals operational costs	Benefits > costs	
Social indicators				
Human health				
15	Cases of gastrointestinal disease reported	Person/year	0	1
16	Aesthetics (colour, odour, etc.)	Satisfactory		
Public satisfaction				
17	Complaint reported to the authority	Number/100 customer/year	0	5
Institutional indicators				
18	Provision of upgrading staffs skill	Satisfactory		
18.1	CPD for engineers	Hours/triennium	150	
18.2	Operators training based on nationally accredited Water Industry Training Package	Satisfactory(>1)		
19	Education and awareness program	Satisfactory		
20	Consumers involvement in decision making	Satisfactory		

opportunity (Anderson et al. 2008). The percentage of water reused in rural Victoria was 30.5% compared to 28.6% in Melbourne in 2007–2008 (ESC 2009), indicating a higher proportion of reuse in country towns and agricultural districts. Water is reused for a tree plantation in Donald, which is one of the oldest forms of reuse (Anderson 2003).

The Willaura system was taken as a case study because it represented an unique situation where the lake discharge was considered as a reuse application in form of environmental flow as promoted by the SEPP. The reuse for environmental flow was implemented in Toronga Zoo and Hawksbury, NSW (Anderson et al. 2008), and can be applied in rural Victoria.

These two case studies are within the service area of the Grampian Wimmerra Mallee Water that serves around 70 000 customers in rural Victoria with a geographic spread of 62 000 km^2, which is about 30% of Victoria (GWMW 2011). The water quality data up to 2005 was used in the indicator analysis. Table 3 provides a snapshot of the two systems in 2005.

The Donald system reused its effluent for a tree plantation with the primary purpose of avoiding inland discharge and evaporating the wastewater into the atmosphere. The local community wanted to develop the resource so the reclaimed water has a potential for greater beneficial reuse. The Willaura system discharged its effluent into the Cockajemmy Lakes, which was against the State Environmental Protection Policy (SEPP) and hence the water authority (GWMW) was planning to stop the discharge. After examining alternatives, the GWMW was considering constructing a 21 ML winter storage and utilizing the reclaimed water to irrigate the adjacent property. However, the effluent discharged into the lake could be considered environmental flow, which sustains the flora and fauna in and around the lake and adds to the aesthetic amenity of the area (GHD 1999; GWMW 2004*c*). The main sustainability issues identified for Donald and Willaura as given in Table 4 are analyzed within the framework of the SIs.

It is not easy to distinctively categorize these issues under the five categories identified earlier — environmental, technical, social and so on — because these issues are interrelated and one aspect leads to other aspects of the problem. For example, a spill into the Richardson River adjacent to the Donald tree plantation can occur due to lack of sufficient storage, which is a technical issue; whereas, the spill itself causes environmental problem.

There are some facets of the SIs that are not applicable to these two systems. For example, they do not cover the groundwater recharge indicators, as they are not intended for that purpose. In addition, applicability of some of the indicators to assess sustainability is not possible due to insufficient data. This in itself may be considered sustainability failure at the institutional level. For example, the design documents of either system cannot be found as the systems operated under different management during the past 50 years. This restricted the study to evaluate technical and economic aspects, such as whether the system is running on its full capacity (designed capacity is not known) and benefit–cost ratio of the system. Despite these limitations, sustainability of these systems can still be assessed on the basis of the remaining information such as quality, quantity, monitoring bores and background concentration and river quality data. As this evaluation is intended to show how the SI can be implemented to assess sustainability of any system; exact figures may not be of high significance. The sustainability of the Donald and Willaura's existing lake discharge systems were examined against the SI and summarized in Table 5. The last two columns represent the state of individual indicators for Willaura and Donald systems. Indicators are analysed and compared against the threshold values. Some indicators are only applicable for one system, for example restoration of environmental flow was not applicable in Donald. Those indicators for which data is not available simply because it was not considered before, monitoring and having a management plan to deal with changing soil quality are identified. Those indicators for which data were not available, for example, SS and BOD of groundwater, were not included in the assessment. A weighted assessment is used for the final sustainability evaluation of the two systems.

5. Sustainability assessment

Multi criteria decision assessment (MCDA) was applied to assess the sustainability of the Donald tree plantation and Willaura's existing lake discharge system. Multi criteria decision assessment is utilized when a decision has to be made to identify a preferred solution based on multiple indicators (Pohekar and Ramachandran 2004). Simple weighted sum model of MCDA applied in this study, are popular and effective (Pohekar and Ramachandran 2004). Detailed review of weighting techniques was not possible due to the limited scope of the study. The main objective of the study was to establish a set of sustainability indicators and demonstrate the application of these indicators in sustainability assessment of reuse systems for rural Victoria. Professional experience and judgment was utilized while assigning the weights in this study, however more scientific based approach can be taken, for example expert opinion, surveys and interviews with stakeholders.

Environmental, technical, economic, social, and institutional indicators were weighed 35, 15, 20, 15, and 15, respectively, with equal weighting on the sub-indicators for each category. In case of quantifiable criteria if the average value of the parameter (such as *E-coli*, BOD, SS) was within the threshold and maximum acceptable value at more than 90% of the times the monitoring was done, the performance of the system was considered excellent and a score of 5 was assigned. Similarly, if the individual compliance is >80%–90%, >60%–80%, 50%–60%, and <50%, a score of 4, 3, 2, and 1 was assigned, respectively, for each of the performance categories. For non-quantifiable criteria such as consumer's involvement, the performance of which can be gauged in relative terms, an ordinal scale based on judgment was used and scoring of 5, 4, 3, 2, and 1 was assigned for excellent, very good, good, fair, and poor performance of the system, respectively. Table 6 lists the scoring criteria for the different indicator categories used in this case study.

To come up with a final rating for an indicator category, average performance of each sub-indicator was considered.

The indicator parameter, for which data was not available, was not included in the scoring. For some indicators that had limited or no data, long-term monitoring was suggested. Data cannot be available unless it is monitored and recorded. Indi-

Table 3. Donald and Willaura reuse systems (Source: GWMW 2004*a*, 2004*b*).

Category	Donald tree plantation	Willaura Lake discharge
Population	1327	288
Location	North central Victoria	Southwestern Victoria
Potable water treatment	Partially treated	Untreated
Average wastewater collected	102 ML/year	29 ML/year
Type of wastewater source	Domestic	Domestic
Wastewater treatment method	Anaerobic and aerobic lagoons	Anaerobic and aerobic lagoons
Class of reclaimed water according EPA Victoria classification	C	C
Reuse option	Tree plantation	Discharge to Cockajemmy Lakes for flow augmentation
Percentage reuse	100%	100%

Table 4. Issues and risks related to the Donald and Willaura reuse systems.

Donald	Willaura
Chances of groundwater pollution due to percolation	Restoration of biodiversity around the Cockajemmy Lakes after altering the reuse
Spill into the Richardson river due to insufficient wet weather storage may impact flora and fauna and cause health hazards to the downstream user	Lack of identifying lake discharge itself as a reuse option
Loss of native flora and fauna around the woodlot and soil erosion from the bank of lagoon	Regulatory requirements raise questions of environmental and economic sustainability
Increased soil salinity due to flooding the woodlot and high evapotranspiration from the tree plantation	Lack of community interest in the alternative system
Poor quality compliance	No management plan for changed conditions in future
No economic return from the woodlot	
Health risk and poor aesthetics	
Lack of community involvement in improving the system	
No management plan for changed conditions in future	

cators that have good recorded data cannot be the only indicators of sustainability. Unavailability of data is an indicator of unsustainability, therefore long-term monitoring was suggested for many indicators. The indicators for which monitoring was not being done, such as for energy, human health, public satisfaction, staff training and skills upgrade, and consumers education; it was recommended to establish a scoring criteria only after monitoring was started and data are available. For aesthetics and ongoing benefit indicators site condition and general observation was considered for this evaluation, however monitoring is recommended and once the data is available, same principle of compliance should be applicable. The final value was obtained by multiplying the weight and score. The system having the highest value was considered the most sustainable. The proposed irrigation system for Willaura was also examined to compare with the sustainability of the existing lake discharge system.

6. Discussion

A weighted assessment was used for the final sustainability evaluation of the two reuse systems, based on the sustainability indicators. The system having highest rank was considered the most sustainable reuse option. Environmentally, the existing Willaura reuse system was more sustainable than the proposed irrigation system and the Donald tree plantation. Technically, both the proposed irrigation reuse and lake discharge in Willaura scored a higher sustainability level than the Donald tree plantation. Economically, as expected, the existing lake discharge in Willaura scored the highest sustainability level, whereas socially both the existing and the proposed reuse options in Willaura scored a higher sustainability level on the basis that in both cases the human health and aesthetics criteria were addressed. Institutionally, the proposed irrigation reuse in Willaura scored the highest sustainability level based on the involvement of the public in the decision making.

The sustainability assessment led to further refinement of the indicators. The quality indicator in the technical category should comply with its beneficial use rather than the classes of water that the treatment plant is supposed to produce. Currently the lagoon systems are supposed to produce class C water according to the annual report of the authority, but in practice it does not meet that criterion, which is fine as long as the quality meets with its beneficial use. Adopting the quality indicator based on beneficial use will take into account the issue of improper use, which was identified as an institutional impediment in the literature. The classification of proper and improper use should not be based on the expected performance of the wastewater treatment plant (WWTP), but what class of water a particular system is producing and whether the use is suitable to that class. Rather the performance of the WWTP should be defined on the basis of what category of water is required for beneficial use and whether the WWTP is able to produce that threshold level of quality. If the reclaimed water satisfies the beneficial use criteria, irrespective of meeting the class criteria (compliance with class A, B, and C), the system should be considered sustainable. Source reduction is also identified as an indicator, which is important for the systems having no other sustainable reuse option such as Willaura. This indicator can provide economically and environmentally sustainable design solutions for future reuse systems.

Table 5. Sustainability assessment against the SIs.

Indicator #	Sustainability indicators	Unit	Threshold value	Max. value	Willaura system	Donald system
Environmental indicators						
Groundwater						
1	Quality of groundwater recharged (comply with EPA guidelines)				(Cockajemmy Lake is a saline groundwater discharge zone)	N/A
1.1	*E-coli*	counts/ 100 mL	0	1	13.64*	2.5*
1.2	SS	mg/L	0	30	Not available	Not available
1.3	BOD	mg/L	0	20	Not available	Not available
1.4	Heavy metal toxicants	mg/L			Not available	Not available
1.5	Salinity level	% of original level	0	±10	–2.56%	5.71%**
2	Quantity of recharged water					
2.1	Monitoring water table and management plan for changed condition	Value per annum	Satisfactory		Monitoring conducted but no management plan for changed condition	Monitoring conducted but no management plan for changed condition
Surface water						
3	Flow into the water way					
3.1	Incidence of un-seasonal flow into the waterway	#/year	0	1	All reclaimed water is discharged to the lake	Incidents occur depending on climatic condition
3.2	Restoration of environmental flow	Annual	Satisfactory		Yes, but conflicts with EPA requirement	N/A
Habitat						
4	Habitat restoration	Annual	Satisfactory		Yes	No
5	Management plan for controlling disease vectors	Annual	Satisfactory		No	No
Soil						
6	Management plan for dealing with changing soil quality	Value per annum	Satisfactory		No management plan except for human contacts	No management plan except for human contacts
Biosolid use						
7	Provision of biosolid use and management plan for excessive biosolid	Annual	Satisfactory		Not examined yet	Not examined yet
8	Quality of biosolid	Per L	Satisfactory		Not examined	Not examined
Technical indicators						
Quantity						
9	Quantity of wastewater reused	% of wastewater generated	50	100	100	100
Quality						
10	Treatment of wastewater (comply with EPA guidelines for respective class of water)	As given in the guidelines	Satisfactory		Partially comply with EPA class C water	Partially comply with EPA class C water
11	Energy consumption for reuse component	As min. as possible	Satisfactory		N/A	N/A
Economic indicators						
12	Benefit–cost ratio	Ratio	1		Design documents not available	Design documents not available

Table 5 (*concluded*).

Indicator #	Sustainability indicators	Unit	Threshold value	Max. value	Willaura system	Donald system
13	Ongoing benefits (to user and society at large)	Yes	Satisfactory		Increased value of property	Negative due to O/M cost of woodlot
Social indicators						
Human health						
14	Cases of gastrointestinal disease reported	cases/year	0	1	Not available	Not available
	Public health protection measure (fencing, notice posted)		Satisfactory		Yes	No
15	Aesthetics		Satisfactory		Yes	No
Public satisfaction						
16	Complaint reported to the authority	#/100 customers/year	0	5	Not known	Not known
Institutional indicators						
17	Provision of upgrading staff's skill		Satisfactory		Yes	Yes
17.1	CPD for engineers	Hours/triennium	150	Not known	Not known	
17.2	Operators training based on nationally accredited Water Industry Training Package		Satisfactory		Yes	Yes
18	Education and awareness program		Satisfactory		No	No
19	Consumers involvement in decision making		Satisfactory		Yes	No

*Out of three monitoring wells, two have satisfactory counts.

**Fluctuation in one monitoring bore is from 27.5% to –35.37%, having a downward trend.

Table 6. Scoring criteria for sustainability indicators.

Indicator category	Indicators	Score criteria
Groundwater (*E. coli*, SS, BOD, salinity, heavy metals)	Individual compliance of the groundwater parameters with either secondary treatment or background concentration (%)	Compliance is >90% of the time – 5 Compliance is >80% to 90% of the time – 4 Compliance is >60% to 80% of the time – 3 Compliance is 50% to 60% of the time – 2 Compliance is less than 50% of the time – 1
	Satisfactory water table monitoring	>10 years monitoring –5, 5 to <10 years monitoring – 4, 2 to <5 years monitoring – 3, 1 to <2 years monitoring – 2, <1 year monitoring – 1
Surface water	Number of incidence of unseasonal flow	0 incidence – 5, 1 incidence – 4, >1 to 5 incidence – 3, >5 to 10 – 2, >10 – 1
	% of reclaimed water used as environmental flow	>90% – 5, >80% to 90% – 4, >60% to 80% – 3, >50% to 60% – 2, <50% –1
Habitat	Satisfactory habitat restoration	If reclaimed water is essential for threatened and vulnerable species – 5, if restores threatened and vulnerable species – 4, useful in habitat restoration – 3, support general biodiversity – 2, no contribution – 1
	Disease vector control	Criteria should be determined after monitoring is started and data is available.
Soil	Salinity, sodicity, toxicity, nutrients, pathogens, boron and having a management plan	Criteria should be established once monitoring is done and data is available.
Biosolid use	Quality, quantity and having a management plan	Criteria should be established once monitoring is done and data is available.
Quantity of wastewater reused	% of wastewater reused	>90% – 5, >80% to 90% – 4, >60% to 80% – 3, 50% to 60% – 2, less than 50% – 1
Quality of reclaimed water	Individual compliance according to EPA's beneficial use criteria (%)	Compliance is >90% of the time – 5 Compliance is >80% to 90% of the time – 4 Compliance is >60% to 80% of the time – 3 Compliance is 50% to 60% of the time – 2 Compliance is less than 50% of the time –1
Aesthetics	Color, odour, general appearence	Site condition and general observation.
Consumers involvement	Consumers involvement in decision making	Decisive – 5, suggestive – 4, advisory – 3, informative – 2, not involved –1

Another aspect that becomes apparent is whether the method of using MCDA is suitable where the average of indicators in each sub-category contribute to the weighted overall measure of sustainability. Such a methodology allows some indicators to have a very poor or zero rating without jeopardizing the score for the whole system. For example, if a wastewater treatment plant continually contributes to disease incidence due to contamination of drinking water supplies, the overall system could score well using the MCDA, but be considered unsustainable within the eyes of the community. Similarly, if data is not available, this could be taken as evidence that the system is not sustainable rather than just omitting it from the analysis. One could argue that collection of data, or evidence as to why data is not collected, on all indicators should itself be a sustainability indicator.

7. Conclusion

In Australia where water is probably the most scarce resource and a number of issues are associated with the reuse of wastewater, having a sustainability assessment tool is essential. The aim of this study was to answer two important questions: what is a sustainable wastewater reuse system, and how can the sustainability of the system be assessed. These goals have been achieved. Identifying impediments to wastewater reuse and interpreting concept of sustainability in terms of wastewater reuse revealed that a sustainable reuse system should be based beyond the three conventional aspects — environmental, economic, and social, generally referred as triple bottom line (TBL) approach — and involve consumers in decision making, address institutional issues and focus on the separate outcomes rather than the output, with a system approach. Sustainability indicators were developed as a tool for sustainability assessment of wastewater reuse systems in rural Victoria, Australia. Five indicator categories- environmental, technical, economical, social and institutional, and 27 Sustainability Indicators were developed. Long-term monitoring and having a management plan was emphasized and recommended for following indicators: groundwater table, controlling disease vectors, soil quality (salinity, toxicants, nutrients, boron, pathogens presence in top layer), and biosolid use. Long-term monitoring allows incorporating new and emerging issues in future. For individual systems depending on data availability further monitoring of present indicators can be recommended.

The two case studies — Donald tree plantation and Willaura Lake discharge systems — demonstrated how the sustainability assessment of existing as well as proposed reuse application can be done on the basis of sustainability indicators. The final sustainability scores were derived using multi criteria decision assessment.

The sustainability indicators can be used as a tool for regulators, managers, and operators to assess sustainability of existing systems and to designers and planners as a guideline for developing future systems. It can also provide a basis to develop similar indicators for other systems.

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