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Smart Water Fund Project 613-001: Best Practice Performance Monitoring for Small Scale Wastewater Treatment Systems

Melissa Toifl[1], Roger O'Halloran[1] and Clare Diaper[2]
[1]CSIRO Land and Water
[2] Water Conscience

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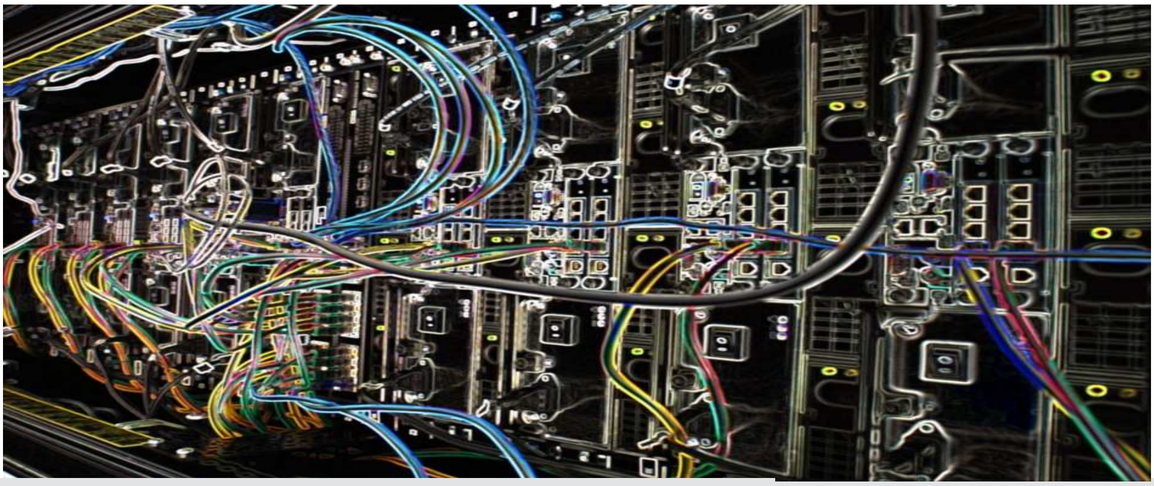

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The authors wish to thank the Smart Water Fund for their financial support for this research project. We also wish to thank the researchers, water utilities, case study participants, regulatory authorities and other government bodies with whom we made contact during the course of undertaking this project to discuss research, technologies and regulations in relation to wastewater treatment and monitoring.

EXECUTIVE SUMMARY

The overall purpose of this project was to undertake a desktop review to identify best practice process and performance monitoring techniques for small scale recycling systems. The project was delivered through four Milestones.

The goal of Milestone 1 was to finalise the project objectives, identify the deliverables and develop a communication plan to be followed during the course of the project and to assist with dissemination of the project outcomes. Milestone 2 involved an extensive literature review of existing and emerging monitoring technologies and techniques for small and large wastewater recycling systems. Milestone 3 included a series of case study investigations of existing small scale wastewater treatment systems to help better understand typical monitoring practices and technologies along with any problems or issues that arise and how they are managed.

This Final Report forms Milestone 4 of the Smart Water Fund project, where the information collected over the course of the project has been collated into a single document. It includes detailed information about sensors, reliability, common faults and problems, and parameters monitored at eight case study sites around Australia and one in the United States. The report also includes recommendations about best practice performance monitoring for small scale wastewater recycling systems.

The findings emphasised:

- The importance of collecting, analysing and interpreting the online monitoring data regularly, so that trends in water quality as well as in the sensors and other processes in the treatment system can be identified.
- That regular maintenance and calibration of sensors and other equipment plays an important role in reliably monitoring the ongoing performance of small scale systems.
- The importance of using quality sensors and equipment designed for the purpose and situation in which they are being used.
- A Hazard Analysis Critical Control Point (HACCP) risk management methodology is essential to identify hazards in different stages of the treatment system and develop appropriate risk management strategies. This then allows CCP parameters to be identified and connected to alarms that can automatically shut down a system in the event of a breach in water quality or other critical fault.
- The ability to include remote monitoring has emerged as a best practice monitoring approach.

- It is essential to have clear responsibilities for system maintenance so that an agreed party is responsible for ensuring that the appropriate action is taken if alarms are triggered, along with documenting alarm details and any corrective actions.

1. INTRODUCTION

Many Australian cities are currently facing water supply shortages through the impacts of reduced rainfall in water catchments and an increase in urban populations. This has led water utilities and regulatory authorities to assess alternatives to the current centralised water supply systems, along with any associated risks to public health and the environment. One option under consideration is to install small scale or decentralised and on-site wastewater treatment plants, which have the potential to make substantial contributions to water recycling, and these are the focus of the current project. Small scale wastewater treatment and recycling plants often use the same physical, chemical and biological processes as existing centralised wastewater and water systems. However, smaller treatment plants are likely to experience a larger variation in feed water quality and quantity as they do not have the same buffering capacity as large scale systems. This has lead to uncertainty as to the suitability of using large scale processes and their associated control systems in smaller scale applications, and a different approach to monitoring small scale wastewater recycling systems is also required. In addition, the responsibility for operation and maintenance of small scale wastewater treatment systems may not reside with the water retailers but may be undertaken by a treatment system manufacturer, body corporate or other small to medium enterprise (SME). This means that treatment systems may not be staffed on a full time basis and so there is a greater need for robust monitoring techniques. In addition, the ongoing monitoring of small scale recycled wastewater systems to control the human, environmental and business risks associated with system failure has often been identified as a barrier to their widespread adoption (Bixio *et al.* 2005).

Whilst recycling wastewater can provide substantial water saving opportunities, it is important to understand that it contains various micro-organisms and chemical components that may present significant health and environmental risks (EPA 2009; EPHC 2006). Therefore, it is absolutely essential that any recycled wastewater is treated appropriately prior to re-use. Treatment may need to include disinfection if the recycled water is used for purposes with potential for direct human exposure, such as surface garden irrigation and toilet flushing. Ongoing monitoring of the treatment, disinfection and storage stages is an important aspect of any recycling scheme to identify any potential problems before the water is re-used.

This project aims to identify best practice performance and process monitoring techniques for small scale wastewater recycling systems, with a specific focus on techniques for controlling potential health and environmental risks. The project summarises monitoring requirements required to ensure that recycled water from small scale treatment systems is fit for purpose on an ongoing basis. It also aims to identify important factors associated with ongoing performance monitoring of small scale systems, including the identification of new and emerging monitoring technologies that are close to commercialisation.

2. PROJECT APPROACH

A detailed project plan was developed (Milestone 1) following clarification of project aims and objectives through consultation with the Smart Water Fund. It was decided that the project should include greywater and wastewater recycling processes, but would not address monitoring requirements for rainwater or stormwater systems. Treatment systems analysed were limited to those not continuously staffed, and whilst potential monitoring system operational issues have been examined, extensive details on monitoring system failures were not provided. Costs of monitoring systems were also discussed, but the financial suitability of systems for a particular end use was not addressed.

For the purposes of this project, small scale systems are defined as those that are not staffed on a full time basis rather than based on size or volume of wastewater treated. Therefore systems treating from thousands of litres per day up to hundreds of thousands of litres per day are included as small scale provided they do not have an operator present on a full time basis.

The project was delivered in three steps outlined in Figure 1; a literature review, a review of case studies, and a final report.

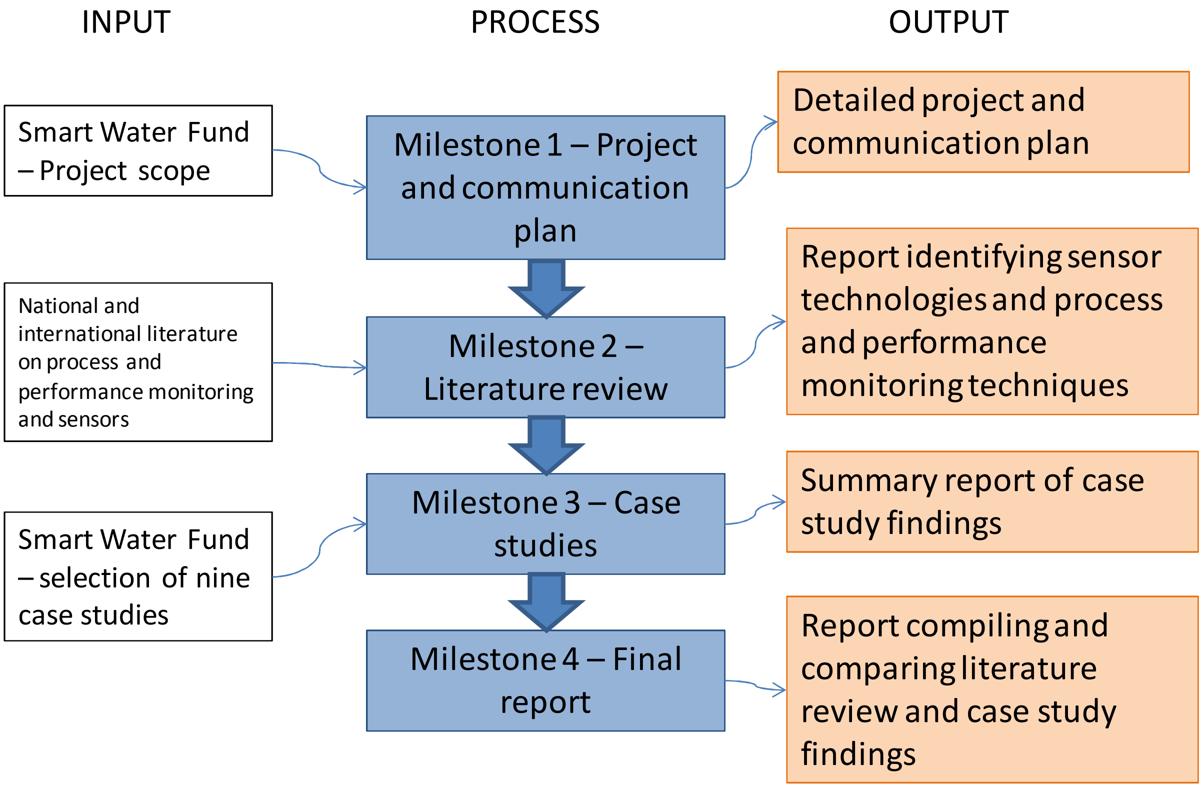

Figure 1: Best Practice Performance Monitoring for Small Scale Wastewater Treatment Systems process flow diagram

An extensive literature review of new and innovative process and performance monitoring techniques (Milestone 2) also considered national and international guidelines for wastewater recycling and other risk assessment frameworks concerning wastewater recycling and management. In addition, the use of online and inline sensors and some of the issues around reliability, failures and calibration and maintenance were also discussed.

A number of case studies were investigated (Milestone 3) to identify monitoring techniques and technologies currently being utilised in the field, in order to better understand how existing monitoring needs were being met. In addition, the case study scenarios provided important information about how well the selected monitoring methods work in practice, along with maintenance and calibration requirements and other operational issues. Collecting information and being able to discuss the technologies and performance monitoring with the operators of existing treatment systems provided valuable insights and information that would not have been possible to obtain through the literature.

The project utilised the Australian Guidelines for Water Recycling: Health and Environmental Risk Management (Phase 1), known as AGWR, (EPHC 2006) along with the recent Guidelines for Validating Treatment Processes for Pathogen Reduction: supporting Class A water recycling schemes in Victoria - Consultation draft (Department of Health 2010) for guidance in the assessment of best practice process and performance monitoring techniques. The AGWR (EPHC 2006) identify four functional categories of monitoring:

1. Compliance or verification testing;
2. Process control;
3. Operation and maintenance;
4. Monitoring for other supporting requirements (i.e. research or employee education).

This SWF project focused on operational and verification monitoring only, and did not cover community and employee awareness and education functions. The requirements for operational and verification monitoring outlined in the AGWR (EPHC 2006) includes a focus on the performance of preventative measures, frequency of monitoring and clarification that operational monitoring should occur throughout the process; whereas verification monitoring takes place where treatment is considered complete, i.e. at the end of the process. The Victorian guidelines (Department of Health 2010) provide a more detailed description of the Class A recycled water scheme validation processes. The current project did not address the monitoring requirements for initial process validation as described in these guidelines but does incorporate requirements for the monitoring of recycled water systems in real time to provide assurance that the water quality objectives are being met continuously.

2.1. Project Scope

This project aims to provide important information in relation to ongoing performance monitoring of small scale wastewater recycling systems to ensure the recycled water is fit for purpose. The objectives were to:

- Identify current best practice and emerging monitoring approaches for control of health risks in small scale wastewater recycling systems.
- Provide an overview of the strengths and weaknesses of the monitoring approaches identified and the treatment technologies to which they could be applied.
- Provide an overview of the practicality of the monitoring approaches, considering the need for specialist services such as calibration and the frequency of such services.
- Provide information about telemetry requirements for integration into centralised monitoring and response systems.
- Provide indicative costs associated with the application of the monitoring approaches.
- Provide an indication of the sensitivity of the monitoring approach for identifying a reduction in treatment plant performance.

3. BACKGROUND

This section contains a brief summary from the literature review as well as information about current regulations, guidelines and monitoring requirements; and is intended to provide some context for this report. The full literature review prepared for Milestone 2 is available from the Smart Water Fund and should be referred to for further information.

3.1. Literature review

The literature review addressed both wastewater and greywater recycling and focussed on monitoring requirements for protection of human health, although environmental monitoring techniques were incorporated where appropriate. Small scale wastewater recycling systems incorporate a wide range of technology types and scales of application. The variation in scale of application means there will be a greater variability in feed flows and quality compared to a large scale wastewater treatment plant (WWTP). The variation in feed flows is largely dependent on the scale of the system. For example, the variation in feed flows for an individual household scale could range from 0 L per day (if the occupants were away) to 1000 L or more per day if there are extra guests staying. Variations would also be expected to occur within each day. In a similar manner, for a typical office block there would be much less flow over weekends and during the night when there are few people at work. For an apartment block there could be peak flows in the morning before people go to work and then again at night as people arrive home, with much reduced flow during the day. In these situations the variations in flow could easily be up to 100,000 L per day. For larger wastewater treatment systems (i.e. neighbourhood or cluster size) the variations will be less as they will be more balanced by people who work different shifts and different days, and also by people who stay home and don't go out to work.

This means that selection of a single sensor or a specific array of sensors or process monitors to cover all small scale wastewater recycling system is not appropriate, and a monitoring method needs to be developed that will allow for these uncertainties and variability. This methodology should incorporate the risk management approach of the AGWR (EPHC 2006) and be complementary to the Victorian EPA Code of Practice – Onsite Wastewater Management (EPA 2009).

A number of innovative approaches to monitoring were identified, including portable multi-sensor remote monitoring, and monitoring of environmental parameters as opposed to components of the treatment system. New methods for process control of large scale wastewater treatment systems may provide novel approaches to the development of best practice performance monitoring for small scale systems, and include methods such as Bayesian networks, fuzzy logic, neural networks and principal component analysis.

Process control and monitoring techniques play an important role in large scale wastewater treatment, and provide an opportunity for early identification of potential problems within the treatment process. Performance monitoring also plays an important role in wastewater treatment, as this is used to directly identify any issues with the water quality. In this review, a large number of process and performance monitoring techniques and technologies were included for both large and small scale treatment systems, in order to cover the broad range of monitoring options available to the wastewater industry.

During the course of the literature review it became evident that there were many different analysers available to monitor parameters online; including those for organic load indicators, nutrients, physicochemical parameters and inorganic ions. However, it is important to note that some of these analysers were not designed for continuous monitoring, and their performance may be less than satisfactory in treatment plants under continuous monitoring conditions. It was also found that manufacturers' specifications were often set under ideal conditions, and did not always accurately reflect the ongoing performance of analysers in continuous monitoring treatment plant environments.

3.2. Current regulations and guidelines

The AGWR (EPHC 2006) specify log reduction values (LRVs) for pathogenic micro-organisms (bacteria, protozoa and viruses) required for different end uses of recycled water. The AGWR (EPHC 2006) also provide indicative log removals for different wastewater recycling unit operations. These LRVs are different for the various microorganisms of concern in wastewater, and range from 0-0.5 log removal for primary treatment processes, to >6.0 log removal for reverse osmosis. The AGWR (EPHC 2006) and the recent Victorian Guidelines (Department of Health 2010) recognise the limitations of traditional end-point water quality monitoring, such as measurement of E. coli or faecal coliforms. Both guidelines recommend the approach of using operational monitoring parameters, such as flow or disinfectant residual, to indicate treatment efficacy and protect public health. This approach allows rapid response to failure, demonstrates the effectiveness of removal of a range of pathogenic organisms, and defines the operating conditions under which the system will perform reliably.

The Victorian Guidelines (Department of Health 2010) identify protozoan parasites and viruses as the most significant pathogens in recycled water schemes, and they are the target pathogen groups for validation. A multiple barrier approach is recommended to minimise the consequences of faults in recycled water control systems, and each treatment process unit in the treatment train must be validated. Validation requires an understanding of the mechanisms of pathogen reduction along with the factors that affect the efficacy of the treatment process unit and therefore the relevant operational monitoring parameters.

Both guidelines (Department of Health 2010; EPHC 2006) recommend that a risk assessment tool, such as the hazard analysis and critical control point system (HACCP), is used to identify factors that affect treatment efficacy, such as transmembrane pressure (TMP) or UV lamp intensity. This information can then be used to identify the operational monitoring required to indicate when these factors are within an acceptable range. This monitoring may involve spot sampling or continuous measurements, and provides assurance that the system is under control and is used to trigger corrective actions to prevent unsafe recycled water being delivered to the end user. The guidelines recognise that while every factor that may affect the efficacy of the treatment process can be monitored, it is often possible to select a few key operational monitoring parameters that can effectively demonstrate efficacy. These key operating parameters are called critical control points (CCPs), and critical limits (CLs) are prescribed for these parameters to ensure that each CCP effectively controls a potential hazard. The Victorian Guidelines (Department of Health 2010) require that real-time monitoring, linked to an appropriate alarm-monitoring system and automatic shutdown, is provided for all critical limits.

The Victorian Guidelines (Department of Health 2010) identify potential CCP operating parameters for a number of different recycled wastewater processes (Table 1). These operating parameters depend on the treatment process, although some are common to many process types (e.g. pH). It is recommended that most of the parameters should be monitored continuously.

Table 1: Summary of recommended operating parameters for recycled water treatment processes (Department of Health 2010)

Treatment system type	Operating parameters
Activated sludge	Mixed liquor suspended solids (MLSS) in reactor Sludge age Loss of aeration in activated sludge reactor Dissolved oxygen concentration Ammonia concentration Sludge volume index (or equivalent) Sludge blanket level Suspended solids concentration Flow (or hydraulic retention time) Temperature Salinity pH Coagulant dose rate (failure or suboptimal)
Media filtration	Floc formation using jar testing, an online zeta-potential meter or streaming current detector (or equivalent) Mixer speed (if appropriate) Hydraulics pH Daily ammonia Temperature Alkalinity Organic content Suspended solids (influent and effluent) Turbidity (influent and effluent) Particle size and distribution (influent and effluent)
Membranes	Direct integrity test (DIT) on each membrane filtration unit Diagnostic testing Online indirect testing (such as turbidity or particle counting) of the filtrate Oxidation reduction potential Flux Transmembrane pressure Temperature
Reverse osmosis	Electrical conductivity (EC) Total organic carbon (TOC) Temperature Flux Permeability System recovery
Membrane bioreactors	Parameters identified in validation pH Dissolved Oxygen Temperature, Suspended Solids Turbidity
Oxidant disinfectants	Online dosed and residual oxidant concentration at end of contact period ORP (not for chlorination) pH Instantaneous flow rate Water temperature Tank hydraulic volume/level Ammonia-to-chlorine ratio (for chloramination) Upstream turbidity Upstream suspended solids Hydraulic flow rate of upstream lagoon sedimentation
Ultra Violet Disinfection	UV intensity through treated water Flow rate Power to lamp

In addition to the parameters identified in Table 1, management and monitoring of backwash sequences and establishment of filter run profiles (i.e. filter run times, filter breakthrough and terminal head loss) is also recommended for media filtration treatment processes.

Apart from these monitoring recommendations the Victorian Guidelines (Department of Health 2010) outline some general operation and maintenance requirements as follows:

- All monitoring equipment associated with CCPs must be maintained and calibrated against a reference instrument or standard at regular intervals to verify that it is within specification.
- The frequency of maintenance and calibration must be in accordance with the supplier recommendations as a minimum, and be underpinned by a risk assessment.
- Calibration requires sign-off by the person conducting the calibration and should be formally documented and auditable.
- Calibration schedules should be reviewed at least annually and should consider manufacturers' specifications, previous data, trends and cross-equipment checks using the same equipment on the same sites.
- Wherever possible, cross-site checks (using the same equipment on several sites) and cross-operator checks (two different people do the same calibration on the same equipment and site) should be conducted.
- A log of reference standards or reference items used must be maintained and documented.

The literature review also incorporated a review of international legislation for small scale recycled wastewater treatment processes. No guidance was identified in European legislation, but the US has adopted a framework approach to the overall management of onsite and decentralised wastewater treatment systems, which includes performance, operation, maintenance and monitoring. This system allows flexibility in approach and development of site specific and appropriate monitoring systems.

3.3. Monitoring Requirements

Monitoring requirements for small scale wastewater treatment systems can vary depending on the treatment technology employed and the end use of the recycled water. However, monitoring can generally be grouped into two main categories: (i) process and (ii) performance monitoring. The level of monitoring required is determined by several factors: the volume of wastewater being treated and recycled, the end use of the water, and local requirements in the state in which the treatment plant is located. Although most states follow the AGWR (EPHC 2006), there are additional requirements in some states. The ongoing operational/verification monitoring for most small scale wastewater treatment systems typically involves a combination of process and performance monitoring.

3.3.1. Process Monitoring

Process monitoring in wastewater treatment plants relates to the risk assessment of the performance of specific components of the process (Rosen *et al.* 2004). Process monitoring involves measuring the performance of the essential components of the treatment process. These are normally identified by undertaking a risk assessment of the process to determine the critical components involved. The process parameters that are typically monitored irrespective of the scale of the wastewater treatment plant include water level, flow and pressure; but may also include pump function and other on/off switches (MacLennan 2010). For systems that are producing recycled water, turbidity and UV lamp intensity are commonly measured parameters. Process control strategies may also be considered within process monitoring. Process control and process monitoring are closely linked, as the monitoring data is required for process control. Process monitoring for fault detection is also commonly utilised to identify failures of system components such as actuators or sensors, for abnormal or crisis situations, and for operational or maintenance requirements (Schraa *et al.* 2006).

Only limited literature was identified describing process control of small scale wastewater recycling systems, primarily due to the paucity of historical operational data and information required to support the mathematical models and statistical approaches used for process control. The literature review identified that many techniques for process control have been developed for larger scale wastewater treatment systems. These approaches have to deal with the uncertainties associated with biological processes, and so may be applicable to the development of frameworks and approaches for smaller scale systems. The approaches include Bayesian networks (Cheon *et al.* 2007), fuzzy logic (Skrjanc 2007) , neural networks (Yu *et al.* 2008) and principal component analysis (PCA) (Jun *et al.* 2006; Lee *et al.* 2005; Lee and Vanrolleghem 2004; Park *et al.* 2005). However, Bayesian networks and PCA both require large datasets to identify significant parameters and develop models, and so may not be appropriate to the data poor, small scale wastewater recycling systems. Bayesian networks do have the ability to self learn from existing data, so may be applicable once some data becomes available.

Another approach used in large scale wastewater treatment that may provide benefit to the process control of small scale recycling systems is that of variable setpoints for different operating conditions. Large scale wastewater treatment plants generally operate to single setpoints, but new approaches have given improved performance when control is adapted depending on current conditions. This seems a more appropriate method for use in small scale processes with variable feed stream quality.

Advances in integrated approaches used to model and control larger scale wastewater treatment systems are also potentially applicable to the decentralised wastewater treatment approach. A number of researchers have suggested extending the boundary for assessment of wastewater process control systems to incorporate sewers and stormwater management (Schutze 1999). Using this approach researchers have identified control objectives (criteria) that are located outside the wastewater treatment system boundary, and have used water quality parameters in a receiving water body, rather than treatment plant effluent quality or discharge volume (Fu *et al.* 2008). Monitoring of parameters outside the physical boundary of the treatment process may provide an alternative to extensive process monitoring, particularly for assessment of environmental health risks e.g. soil/groundwater/soil moisture sensors (Hummel *et al.* 2001; Konukcu *et al.* 2003; Paige and Keefer 2008; Rudnitskaya *et al.* 2001). These sensors could be part of the wastewater system process control in that, if detrimental environmental effects were monitored, process variables could be changed to improve system performance or initiate system bypass to sewer.

3.3.2. Performance Monitoring

Performance monitoring refers to the assessment of water quality delivered from a device/process, and it may require analysis of a number of different parameters that are often dependent on the final use of the water. Performance monitoring is of particular importance in recycled water systems to ensure the quality of the treated water is fit for purpose on an ongoing basis (EPHC 2006). Performance monitoring may involve chemical, physical and biological parameters as outlined below.

New techniques for process and verification monitoring include biosensors (Melidis *et al.* 2008; van der Schalie *et al.* 2004), microelectrode arrays (Gobet *et al.* 2003), chemical sensor arrays (Bourgeois *et al.* 2002), optical methods (Gutierrez 2009; Sutherland-Stacey *et al.* 2009), fluorescence methods (Baker *et al.* 2004; Henderson 2009), flow injection analysis (Pedersen *et al.* 1990) and remote monitoring (Jaiswal and Lus 2009). Biosensors have found application in verification monitoring of large scale wastewater recycling systems through PCR techniques. Fluorescence methods have been applied to reverse osmosis operation. These techniques are outlined in more detail in the full literature review undertaken as part of Milestone 2 of this project.

Some of the technologies and techniques presented in the literature review had limited potential for use in ongoing performance monitoring due to onerous calibration and maintenance requirements. The reliability and ongoing performance of the various techniques and technologies also needs to be investigated further.

Chemical and physical parameters provide information about the quality of the water. Commonly measured parameters in recycled water include residual chlorine levels (free and total), pH, dissolved oxygen (DO), electrical conductivity (EC), suspended solids (SS) and turbidity. Other parameters that are less commonly measured but still provide an indication of water quality include oxidation reduction potential (ORP), temperature and particle counts.

Microbiological parameters are typically monitored in both potable and recycled water systems to provide information about the level of microorganisms that might be present in water. This information may then be used to make decisions about the level of disinfection that is required, and to monitor the effectiveness of disinfection procedures. However, at this time technology does not yet exist for them to be monitored continuously online, with most analysis having a minimum turnaround time of at least 12 hours thus limiting their usefulness for performance monitoring.

4. CASE STUDIES

A major component of the project involved undertaking a number of case studies to determine the ongoing performance monitoring carried out at these sites, as well as to better understand the monitoring requirements of the different sites.

4.1. Case Study Site Selection

The case study sites were selected to give a broad representation of different treatment processes, source waters (i.e. greywater and blackwater systems), end uses for the recycled water, as well as a range of treatment volumes (Table 2). The sites chosen were located in Victoria, New South Wales, Queensland and the USA. Whilst most of the sites operated on a continuous basis, one site was being operated as a batch process. More information about the case studies is presented in Section 4.4.

4.2. Data Collection from Case Studies

A detailed survey was carried out at a number of sites that currently have operational small scale wastewater treatment plants, to determine the performance monitoring technologies and techniques in place within these systems. A set of questions (Section 4.3) formed the basis of a questionnaire for each site. This had 3 main sections and was used to ensure that consistent and comparable information was collected from all sites. The first section aimed to collect background information about the site and the wastewater treatment plant. The second section was designed to collect detailed information concerning the process and performance controls within the treatment plant. The last section of the questionnaire was based around verification monitoring to gain an understanding of the ongoing monitoring used to ensure correct performance of the system. Where possible site visits were carried out to ensure a proper understanding of the wastewater treatment system, and further information was also collected concerning false alarms and operational issues.

4.3. Questionnaire

The questionnaire was developed based on discussions with the Steering Committee and using information from a Water Environment Research Foundation (WERF) report (MacLennan 2010).

The information requested from the case study participants included the following:

Background

- Where is the case study site?
- What type of building/facility does the system serve?
- Which wastewater streams are collected and what is the volume processed?
- What is the type of wastewater treatment system?
- When was the system installed, and when was it first fully operational?
- What are the end uses for the treated water?
- Was there a project champion and who was this?

Process/performance control

- Describe the unit processes.
- Was the system pre-commissioned in controlled conditions prior to full operation?
- What are the monitoring systems for each of the unit processes? Continuous, inline, online, lab analysis, how often?
- Where in the unit process are the sensors located (i.e. at inlet/outlet, in bulk, and how was this decided)?
- What do the monitoring parameters control (i.e. what are the interlocks/ failsafe/ operational limits)? Is telemetry used for communication of alarms to operators?
- How often are these sensors maintained and/or calibrated? What resources are needed for maintenance and calibration? How much do these resources cost?
- How often is someone on site at the treatment facility?
- Feedback/comments on false alarms/operational issues.
- What was the approximate capital cost of the sensors and how does this relate to the overall project budget?
- What was the process followed to identify monitoring requirements?
- Which regulatory authorities were involved in this process?
- Were the water quality parameters monitored identified as critical control points?
- Is monitoring data collected by a centralised control facility? Is there any analysis of the data collected? What analysis is carried out? How is this analysis used? What process control techniques are used?

Verification monitoring

- Has additional verification monitoring been undertaken?

- What parameters were measured for verification monitoring? How were they analysed, what samples were taken, how frequently were samples taken, were samples taken in duplicate/triplicate?
- How was the verification monitoring program developed? Who was involved?

4.4. Case Study Results

The results for the case studies showed that there were a range of process and performance monitoring technologies and techniques being used. Most of the sites used a combination of process and performance monitoring methods to meet their ongoing monitoring requirements. All of the process and performance monitoring tools being used at the case study sites had been identified in the literature review. It was found that seven of the nine sites used Hazard Analysis Critical Control Point (HACCP) risk management methodologies to assist with designing their monitoring requirements and critical control point alarms. The sites with HACCP plans were established more recently than those without, suggesting that the use of HACCP in the wastewater industry may still have been in its infancy when some of the older systems investigated were established. Sites with CCPs in place also had detailed documentation of the procedure to follow in the event of a CCP alarm being triggered, along with requirements for documenting significant details about the alarm and the response, actions taken and any other actions required.

More details on the greywater and wastewater system components of the case studies are provided in Table 2. Some sites also had rainwater or stormwater collection, treatment and use systems, but as these are not in the scope of the study they were not included here.

Table 2: General case study site information

Site	Source of wastewater	Volume treated/capacity (per day)	Treatment train	End Use
A	Blackwater	3,000 L	Primary settlement tanks/ balance tank/ aeration tank including magnesium hydroxide dosing/ hollow fibre MBR (Membrane Bio-reactor)/filtration (coarse, medium, fine)/disinfection	Toilet flushing / sub surface irrigation/ supply to water feature
B	Greywater	10,000 L	Balance tanks/ pre-treatment tanks including screening and aeration/ biological treatment tank / ultrafiltration/ disinfection	Toilet flushing / open space irrigation
C	Greywater	2,500 L	Primary screen and collection tank/ trickling bed biological filter/ultra-filtration	Toilet flushing/ sub surface irrigation
D	Greywater	15,000 L	Coarse filtration and screening/ activated sludge and aeration tank/ MBR/disinfection	Toilet flushing/sub surface irrigation
E	Blackwater	97,500 L	Screening/ balance tank/ aeration tank/ MBR/disinfection/contact tank	Toilet flushing
F	Blackwater	720,000 L	Screening/ flow distribution tank/ primary settling (anoxic)/ aeration/ secondary settling (anoxic)/ membrane filtration (MBR)/ disinfection	Some recycled water used on site at STP. Treated water discharged into a sensitive river environment
G	Blackwater	60,000 L	Primary settling tanks (anaerobic digestion)/ trickling bed filters/ Continuous micro-filtration/ disinfection	Toilet flushing, surface irrigation and car washing
H	Blackwater	250,000 L (operated as batch process)	Primary holding tank with aeration and mixing/ High velocity sonic disintegrator (HVSD) /sand and mixed media filtration/ micro-fine bag-filter (ultra filtration and RO if required) / disinfection	Toilet flushing, surface irrigation, car washing and irrigation for a large native plant nursery. Also used to supplement fire fighting water supply if required
J	Blackwater	1,000,000 L	Modified trickling filter over a clarifier	Drip irrigation

4.5. Process Monitoring

All of the case study sites investigated for this project incorporated process monitoring as part of their ongoing monitoring strategies. Some sites monitored several processes as outlined in Table 3 below. All case study participants identified process monitoring as a key requirement to ensure that the treatment system was operating within its control limits. The parameters monitored varied, however most systems included level sensors (such as float valves), with a number of them also monitoring flow. Other parameters included flood sensors, pressure switches and pump function. Sites using membrane-based technologies often used pressure sensors and they also monitored wastewater temperature as membrane performance can be affected by the viscosity of the permeate and concentrate.

Level sensors were typically used to monitor the level of wastewater in a particular section of the process. However, in some systems they were also used to trigger other processes and to move the wastewater along the treatment chain (i.e. once a particular level was reached, a pump or valve was triggered to move the water onto the next stage of treatment). Flow sensors were used in a similar manner to monitor the level of flow through the system. This is particularly useful for determining any problems with flow in the system (e.g. blockages or pump/valve failure, etc). These types of sensors can be extremely valuable if they are monitored regularly or connected to an alarm system that requires an operator to respond.

As outlined in Table 3 below, seven of the sites used level sensors to monitor the wastewater throughout the treatment process and in the various tanks. Included with level sensors were float valves and hydrostatic level measurements. At least one site utilised magnetic float level probes and one site used hydrostatic level sensors. Flow sensors were also commonly used, with five sites specifying their use. Pressure sensors including trans-membrane pressure featured most commonly in systems based around membrane technologies. Other process variables monitored included pump function at three sites and pressure in the supply lines as well as pressure switches and aeration. One site also had flood sensors installed. For most case study sites some of the process monitoring parameters were connected to alarms that could shut down the treatment plant. It was also found that for most sites, some of the process parameters formed part of the CCPs in the HACCP schedule.

Table 3: Process monitoring parameters used at case study sites

Parameter	Case Study	Comments
Water level sensors (including float valves, magnetic float level probes and hydrostatic level)	A, B, C, D, E, F, G, H and J	All case study sites included some form of monitoring for level
Flow Rate Sensors	A, E, D, F and G	
Flood Sensors	A	Installed as an added precaution to warn if the system should fail and flooding occurred
Pressure Sensors (including TMP and hydrostatic pressure transmitter)	A, D, E and G,	Commonly used at sites that use MBR
Pump Function	A, G and J	Used to monitor whether pumps are operating properly
Pressure Switches	B	
Pressure	D (supply lines)	
Aeration	D (for MBR)	
Temperature	E (monitored on the local transmitters for pH, EC & pH/FAC (free available chlorine) and manually logged), F (measure temperature at the permeate inlet suction for each membrane and also in the secondary anoxic zone at the end of each bioreactor).	Temperature of the incoming wastewater is a critical parameter in MBRs as temperature affects the viscosity of the permeate and the concentrate.

4.6. Performance Monitoring

Performance monitoring provides important information about the treatment system and describes both the operational (continuous in-plant monitoring), and verification monitoring which ensures CCPs effectively control potential hazards. The monitoring that occurs within the treatment plant is discussed further in Sections 4.6.1 and 4.6.2.

Ongoing performance monitoring is a regulatory requirement in Victoria for treatment plants that discharge to the environment and have a design capacity less than 5 kL/day. Currently in some other states of Australia, similar systems may only require a permit with local council rather than a licence agreement with State Government health or environmental authorities. Most of the case study sites in this report had a licence agreement with State environmental or health regulatory authorities. A licence agreement typically requires regular independent performance monitoring to be carried out that includes collecting samples for offsite analysis of physical, chemical and microbiological parameters. The frequency of sampling varied, but can be fortnightly for new systems, whilst monthly or bi-monthly sampling is common for well established treatment plants. The monitoring is normally done by an accredited external company and involves collecting and analysing samples for chemical and microbiological parameters such as pH, EC, BOD, suspended solids and bacterial counts such as *E. Coli*. A report is then prepared and the results of the independent analysis are reviewed. If the analysis shows that all of the parameters analysed are within the range specified in the licence agreement, typically no further action is required. If the results show that some of the parameters are outside of the range for the licence agreement, then the owner/operator of the treatment system must advise the regulatory authority that they have breached their licence conditions.

Audits by the regulatory authority can be conducted at any time and independent reports must be made available at these audits to prove that any licence breaches have been reported. The sanctions for breaching licence conditions vary depending on the severity of the breach and how often a breach has occurred.

However, in Victoria all systems providing Class A recycled water will need to comply with Guidelines for Validating Treatment Processes for Pathogen Reduction (Department of Health 2010) currently in draft form, which require more stringent monitoring for ongoing treatment system verification.

4.6.1. Current parameters

For continuous monitoring within the treatment plant, it was found that some of the parameters identified in the literature as being currently used for performance monitoring in wastewater treatment processes (Table 4), were also the typical parameters employed in the case studies (Table 5). Turbidity, free chlorine residual and pH were the most commonly monitored parameters, followed by DO, ORP and EC. Suspended solids were being monitored at 2 sites and one site also had an online particle counter in addition to turbidity.

Even though online methods have recently become available for COD and BOD, they were not used at any of the case study sites investigated. Whilst environmental monitoring was being carried out at some of the sites, soil/groundwater moisture sensors were not employed.

Table 4: Current parameters used for performance monitoring in wastewater treatment processes

Parameter	Comments	Wastewater treatment process
EC (Electrical conductivity) (inline measurement)	Simple manual or online measurement.	Often used in wastewater treatment (small and large scale systems).
COD (Chemical oxygen demand) (online measurement)	Provides a measure of oxidisable material in the water. Standard test takes a few hours to complete although quicker and online methods are now available (PeCOD).	Commonly used in wastewater measurements (mainly used in large scale systems through standard laboratory tests).
BOD (Biochemical oxygen demand) (online measurement)	Provides a measure of biodegradable organic matter, but has a 5 day turn-around time.	Often a regulatory requirement for wastewater treatment plants (small and large scale systems - small scale systems required to prove BOD removals in initial testing and may be required for ongoing performance monitoring).
pH (inline measurement)	Used in most aspects of water supply and wastewater treatment.	Wastewater treatment plants (used by small and large scale systems).
Microbiological indicators (currently mostly laboratory measurements but new rapid online methods may become available)	Commonly used to monitor the quality of the waste/recycled water, however traditional methods require long incubation times. New, more rapid methods are becoming available.	Wastewater treatment plants/small scale systems.
Chlorine (inline measurement)	Monitoring system must be reliable as system failure may result in production of unsafe recycled water.	Disinfection control in many small scale systems as well as large systems with wastewater recycling.
ORP (Oxidation Reduction Potential) / DO (Dissolved oxygen) (Inline measurement)	Intelligent diagnosis using commonly measured parameters such as ORP and DO. Possible to use ORP and DO for real-time process control.	Small scale wastewater treatment plant/ sequencing batch reactors, MBRs and large scale wastewater treatment plants.
SS (Suspended solids)	Useful indicator for how well treatment is working	Wastewater treatment plants (small and large scale systems).
Turbidity (Inline/online measurements)	Useful for determining the quality of water – often a regulatory requirement.	Wastewater treatment plants (small and large scale systems).
TOC (Total organic carbon) (Online Measurement)	Provides a measure of organic carbon in a sample. Provides information about water quality.	May be monitored by small and large scale systems during routine laboratory analysis.
Soil/groundwater/soil moisture sensors	Ability to monitor the use and effects of recycled water on the soil.	Environmental monitoring (most likely used for small scale/individual household systems to ensure the soil/vegetation and plants are not adversely impacted by the use of recycled water).

The continuous performance monitoring carried out at the case study sites was mostly inline as outlined in Table 5 unless otherwise specified. The parameters measured were often utilised to determine particular aspects of the treatment process. For example, monitoring the turbidity can be useful to understand how UV disinfection might be affected. DO and pH are often monitored in MBRs to ensure the correct conditions are achieved for successful treatment. Monitoring free chlorine residual in the treated water can provide information about the microbial quality of the water before it is sent for re-use.

The case study sites that supplied recycled water for purposes with potential for direct human exposure (such as garden irrigation and toilet flushing) had the most extensive disinfection procedures. As expected, systems that supplied recycled water for sub-surface irrigation did not have the same level of disinfection built into the system. However, it should be noted that in NSW disinfection is mandatory regardless of whether the recycled water is used for sub surface or surface irrigation. The only two disinfection methods used at the case study sites were chlorination and UV.

Seven of the nine sites investigated used chlorination for disinfection of the treated water as shown in Table 5. At one of the sites, only treated water recycled for use on site was chlorinated. The rest of the treated water from this site was discharged into a sensitive ecosystem without potential for human exposure and so was not chlorinated.

Table 5: Performance monitoring at the case study sites

Parameter	**Case Studies**	**Comments**
EC	A , E	
pH	A, B (inlet and outlet), D, E, ,F G and H	Only site C did not monitor pH
Chlorine	A (manual checks of chlorine daily), B, D, E, G H (free chlorine)	Site F chlorinates only water recycled for use on site. Sites C and J do not use chlorination
ORP (Oxidation reduction potential) / DO (Dissolved oxygen) (Inline measurement)	A (ORP for chlorine), B (DO), D (DO), E (DO), F (DO and ORP), J (DO)	
SS (Suspended solids)	F and H	
Turbidity (Inline/online measurements)	B, D, E , F, G and H	Sites A, C and J did not monitor turbidity
UV	B (UV transmissivity and intensity), C, (UV lamp function (i.e. on/off)), D (UV lamp function),E, F(intensity and transmissivity), G, J	D monitors lamp function rather than intensity A and H do not use UV disinfection
Particle counting	D	Monitored in addition to turbidity at this site
Microbiological indicators	Most sites via regular grab samples	Lab tests (not continuous/online)
ML (Mixed Liquor)/ MLSS (Mixed liquor suspended solids)	A, D, E, F	Monitored to determine the health of the bioreactor

Of the two remaining sites that did not use chlorination, one used the treated water for sub-surface irrigation with little potential for direct human exposure, and the other site used UV disinfection only.

Seven of the case study sites used UV disinfection, and five of the sites that used chlorination for disinfection also used UV disinfection. Two sites used UV disinfection only, with one of these sites supplying water with potential for direct human contact, which could be of concern.

Chlorination methods were found to vary between sites. Most sites used online hypochlorite solution dispensing systems, although some had trialled chlorine tablets. The chlorination step at most sites formed one of the CCPs and therefore was designed with an alarm that would alert when a potential problem occurred. Free chlorine was the most commonly monitored CCP; however one site used ORP as a surrogate means of monitoring the residual chlorine from the disinfection stage. The Victorian Code of Practice for Onsite Wastewater Management (EPA 2009) recommends the use of a colorimetric method for determining the residual chlorine levels.

The monitoring of UV disinfection also varied between sites. Only two of the sites measured UV transmissivity and both of these also monitored UV intensity. A further three sites with UV disinfection monitored UV intensity. Two of the sites monitored lamp function (i.e. on/off) along with run hours, and one of those sites replaced the UV lamps on an annual basis. At least one of the sites monitoring lamp function (on/off) also carried out regular UV transmissivity testing on grab samples. For the sites that did not monitor intensity or transmissivity online, the main reason cited was because of the costs involved.

Whilst monitoring UV lamp intensity or lamp function can provide information about whether the lamp is working and if the expected lamp intensity is being maintained, neither of these parameters on their own provide information about how effectively the UV is treating the water. This is because factors such as absorbance and scattering will not affect UV lamp intensity or lamp function but could result in the dose of UV delivered being significantly reduced. UV absorbance or UV transmittance measurements incorporate the effects of absorption and scattering. Therefore a more effective measure is to monitor UV transmissivity or UV intensity (measured by a UV sensor) along with flow rate, lamp status and UV absorbance to establish and control the UV dose being delivered to the treated water (USEPA 2006).The placement of the UV and chlorination systems varied little between sites. As expected the disinfection stage was always at the end of the treatment chain, however the order of the disinfection steps was found to vary. Four of the sites had UV disinfection before chlorination and then maintained the chlorine residual in the treated water storage tank. The other site chlorinated the treated water first just prior to the storage tank (where the chlorine residual was maintained) and then followed with UV disinfection on the treated water as it was being discharged for re-use.

None of the sites reported problems with disinfection that would have allowed water of questionable quality to be recycled and used. Two of the sites reported they had problems with the disinfection step during commissioning or early stages of operation as reported in Section 4.11; however these problems had been resolved rapidly.

Seven of the nine sites monitored pH, and one site was monitoring pH at both the inlet and outlet. Sites that utilised MBR as the treatment process commonly measured pH to ensure the correct range in the wastewater prior to the bioreactor. Some sites also monitored the pH of the treated water in the storage tank. Parameters such as pH, EC, dissolved oxygen and turbidity in the final treated water often form part of the discharge requirements specified in the licence conditions.

EC was only monitored at two of the sites, both in Victoria. One site monitored EC in the final treated water storage tank whilst the other monitored EC after treatment but prior to the final disinfection step. The end uses for these two sites were respectively, toilet flushing/subsurface irrigation and toilet flushing only.

Oxidation reduction potential and dissolved oxygen were also monitored commonly, with five of the sites indicating that they measured one or both of these parameters. Dissolved oxygen was commonly monitored in the aeration tanks at sites that utilise membrane bioreactors or other biological treatment processes to ensure adequate COD removal and ammonia oxidation.

Suspended solids were only monitored at two of the sites. One of those sites discharged the treated water into a sensitive river ecosystem hence the importance of monitoring suspended solids. The other site used a batch process system and suspended solids monitoring forms part of the licence conditions for the treatment plant. In this situation whilst the analysis was not online, it was completed prior to the treated wastewater being sent out for re-use. Being a batch facility, there was an option for the treated wastewater to undergo further treatment before re-use if parameters were out of range.

Turbidity was monitored online at six of the sites. A maximum turbidity level is often a parameter included in licence conditions. At one of the three sites not monitoring turbidity, the end use for the recycled treated water was sub-surface irrigation; hence the level of monitoring was reduced. Both sites that monitored suspended solids were also monitoring turbidity online.

Interestingly, turbidity was being monitored in different locations at the different sites. Two of the sites measured turbidity in the final treated water storage tank, with one of those sites being the batch processing facility. Three sites monitored turbidity at the end of the filtration unit prior to disinfection, with one of these sites also monitoring particulates via a particle counter on the outlet of the final storage tank. The final site which releases the UV disinfected water directly into a sensitive ecosystem was monitoring turbidity after UV disinfection. However, it should be noted that turbidity is one of the CCPs at this site and in the event of the turbidity increasing above acceptable levels discharge is stopped and the recycled water recirculated back to the membrane bioreactor for re-treatment.

4.6.2. Innovative Parameters

Whilst the literature review in Milestone 2 had identified a number of new techniques and technologies for monitoring performance in wastewater (Table 6), none of the case study sites investigated was planning to implement any of these new methods. As previously mentioned, most of these techniques are still in the development phase. Further research and field trials would be required to prove the reliability, accuracy and maintenance and calibration requirements of these methods before they could become standard practice in small scale wastewater treatment systems.

Table 6: New and innovative techniques for monitoring performance in recycled water and wastewater treatment processes

Technique	Comments
Biological or bio-sensors	Simple, robust and reliable sensors able to detect contamination events quickly.
BOD sensors	Rapid BOD analysis can measure BOD in minutes rather than days. Some issues with reliability for differing sample compositions.
Phosphate sensor	Different methods (e.g. novel microfluidic lab-on-a-chip, or application of various multivariate techniques to wastewater treatment plant data)
Nutrient sensors	Online measurement of nitrate, ammonia, phosphorus for process control.
Microelectrode array	Good reliability for monitoring disinfection agents such as free chlorine. Accurate measurements over several months without loss of sensitivity.
Chemical sensor array	Results show how a chemical sensor array based system can be used for real-time process monitoring.
Optical methods	Spectra obtained will vary significantly depending on the contaminants present.
Fluorescence methods	Distinct fluorescence spectra are observed for wastewater and treated wastewater. Fluorescence is currently an area of great interest for the wastewater industry.
Flow injection analysis	System presented still suffers from unsatisfactory long term stability.
Remote monitoring	Enables technologies to be monitored without the need for site visits. Allows the use of alarms to indicate system faults and failures.

4.7. Sensors

Sensors may be used to monitor process variables including physical parameters such as level, flow and pressure, and performance based parameters including turbidity, pH, chlorine residuals and other water quality parameters. All case study participants were asked for detailed information about the sensors in place at their site including information about manufacturers; location in the treatment process; reliability, accuracy and calibration and maintenance requirements; as well as other interfacing requirements and any other issues experienced.

Understanding the capability of the sensors employed in a small scale wastewater recycling system is an important aspect in successfully monitoring the ongoing performance of such systems. Potential sensor issues and failures and their possible impact are better understood when the capability of the sensor is taken into consideration. A good understanding of the sensors and how they work helps to ensure that they are used correctly and that any problems and failures are detected rapidly.

4.7.1. Reliability and Accuracy

The reliability of sensors is an issue that requires careful consideration when employing them for ongoing monitoring purposes. Sensors may suffer from numerous problems including fouling and drift. Therefore, an understanding of calibration and maintenance requirements as well as the potential problems that may occur with individual sensors is essential to ensuring the information collected is accurate and reliable.

The reliability of sensors may also vary depending on the parameter being measured. For some parameters (e.g. EC) the sensors are often more robust than for other parameters such as pH, chlorine or turbidity. This means that some sensors will require very little maintenance and calibration whilst others will require significantly more attention.

All case study participants were asked about the reliability of the sensors installed at their sites, including how this was measured (i.e. testing against calibrated portable field instruments or versus grab samples). Most sites indicated that they regularly checked sensors against portable field instruments as well as collecting grab samples for analysis. The frequency of this testing varied for the different parameters and sites, but was found to be between weekly and monthly for many of the parameters. Alarm and CCP parameters were monitored more frequently. A common feature was that very few reliability issues were reported. Most sites reported that they had only replaced one or two sensors in the previous 4-5 year period, with some sites reporting no new sensors. On further questioning it was discovered that most sites had very sophisticated and expensive sensors in place, most commonly sourced from either Royce or WTW. Location of the sensors in the wastewater treatment process was given particular attention, with particular note as to whether they were mainly in treated water and therefore not exposed to the fouling influence of raw wastewater. However, for most sites this was not found to be the case, many sensors were located on the raw wastewater side of the plant to monitor both process and chemical parameters such as level, flow, pH and dissolved oxygen.

Selecting the correct sensors for the application in which they will be used is a very important factor and will affect reliability. Most companies have developed specific sensors for different environments to cover both the wastewater and treated water side of the plant. Sensors to be exposed to wastewater may be manufactured from materials more suited to that environment. In addition, many manufacturers are now offering self-cleaning designs and surfaces for sensors being used in wastewater applications.

Sensor accuracy is another issue that requires careful consideration for ongoing monitoring. Sensors, particularly those with optical lenses, may suffer from fouling problems that can cause drift and affect the accuracy of the results.

At some sites, the sensor data was plotted and checked regularly to ensure that any drift or other accuracy problems were detected and resolved rapidly. This is of particular importance for sensors used to monitor CCPs to ensure that sensor drift does not trigger false alarms. Some sites used statistical process control in the form of control charts to monitor the incoming data on a continuous basis. If the parameters monitored move outside the upper or lower control limits then this can trigger alarms. Operators looking after sites that are remotely monitored also indicated that they would log into the system at least daily to check for unusual events or sensor drift. At least one site also conducted a weekly meeting to analyse and discuss the data collected as part of the site plan for ongoing improvement, safety and system optimisation.

4.7.2. Maintenance and calibration requirements

It was found that all case study sites had a routine maintenance schedule in place that incorporated the maintenance and calibration specifications outlined by sensor and other equipment manufacturers. However the routine maintenance and calibration schedule devised often also forms part of the licence agreement and is normally based on various factors in addition to the calibration and maintenance requirements of the sensors. For this reason, routine (including preventative) maintenance may occur more frequently than required by the manufacturer. On the other hand, corrective maintenance (to remedy equipment or sensor failure) is mostly covered in the HACCP plan and includes a detailed procedure documenting corrective action to be taken and keeping appropriate records.

For a number of the case studies it was found that representatives of sensor manufacturers had been involved early in the project to provide advice about the sensors available and their capabilities for particular applications.

4.8. Comparison of recommended sensors at case study sites

A number of parameters were identified in the literature review (Milestone 2) that could provide important information about the performance of treatment systems. Some of these parameters can be readily monitored via online sensors, including (but not limited to) pH, turbidity, DO and ORP. The technologies on which these sensors are based tend to be well developed, accurate and reliable. It was found that all case study sites monitored at least one of these parameters, and most included all of the parameters that had been identified as being important in the literature.

4.9. Remote Monitoring and Telemetry

Remote monitoring and the corresponding telemetry systems were identified in the literature review as being key elements in ongoing performance monitoring (Jaiswal and Lus 2009). The literature review also identified that there were continuing advances in this field (Fogelman *et al.* 2009; Nivert *et al.* 2009). As telecommunications advances, this will continue to drive significant improvements in remote monitoring applications. Another major factor is that the reduced cost of high quality telecommunications ensures that remote monitoring applications become cheaper and therefore more readily accessible.

As expected, remote monitoring was used at most of the sites, but the level of remote control varied significantly. Some sites had remote control over most operations at the treatment plant, including the ability to open and shut valves and turn pumps on and off. Other sites had more basic monitoring, which allowed operators to check the status of the system remotely but did not allow them to alter the state of valves and pumps.

Several of the sites, particularly those where community volunteers or non-skilled staff were responsible for maintaining operations at the plant on a day to day basis, were also being monitored remotely by a parent company. This was to ensure appropriate assistance could be provided in the event of a problem occurring that was outside the scope of the staff managing the treatment plant.

Data telemetry from the sensors at the plant was also enabled at many sites allowing operators to assess the performance of the sensors remotely.

As shown in Table 7, seven of the sites (A, B, D, E, F, H and J) had significant telemetry and remote monitoring in place, with the ability to control various components of the system remotely including switching valves and pumps on and off. The most commonly used remote monitoring system included a programmable logic controller (PLC) with telemetry for remote access and was used by five of the seven sites (B, D, E, G and J). One of the sites that is owned and operated by a water utility utilise their own system based which is purpose-built and is an upgrade on the supervisory control and data acquisition (SCADA) system used in the past by this water utility. However, it should be noted that SCADA systems are not obsolete or outdated, and are still commonly used by many water utilities and other industries.

Two sites had a basic remote monitoring system in place that allowed dial out for significant alarm conditions related to disinfection. This enabled a text message (sms) to be sent in the event of a significant problem with the UV disinfection at one site, or problems with chlorination at the other site. For both sites there was no dial-in option to check on any of the parameters or the plant. One of these sites has put forward plans to install a more sophisticated remote monitoring and telemetry package but was awaiting budget approval at the time of the case study.

Table 7: Telemetry and remote monitoring at case study sites

Case Study	Telemetry and Remote Monitoring	Parameters monitored remotely	Comments
A	BAS (Building Automation System)	EC, pH monitored remotely	Real time data on performance, ongoing monitoring and maintenance by an external company
B	PLC with telemetric add on for access	All parameters listed in Table 5	The parent company has a custodian for each plant.
C	Remote monitoring with dial out for significant alarm conditions (greywater system only)	UV lamp function	Very basic remote monitoring system
D	PLC with telemetry dial out	Level/flow sensors, TMP and all parameters listed in Table 5	Current maintenance contract is with a water utility
E	Touch screen PLC with SCADA (supervisory control and data acquisition)	All parameters listed in Table 5	Ongoing monitoring and maintenance by an external company
F	Upgraded SCADA system incorporating integrated instrumentation, control, automation and telemetry	Level sensors, pressure sensors, and all parameters listed in Table 5	Owned and operated by water utility
G	PLC with telemetric add on for remote access	All parameters listed in Table 5	Ongoing monitoring and maintenance by an external company in addition to onsite volunteers
H	This treatment plant processes wastewater by a batch system during which time an operator is on site. Currently no remote monitoring/ telemetry in place. Some parameters monitored can trigger an alarm.	Disinfection parameters can trigger an alarm	Wastewater treatment plant managed and operated by a consulting company. Plans to install some remote monitoring and telemetry, however awaiting budget approval from the land developer.
J	PLC with remote wireless telemetry with an integrated auto dialler	Pump function, alarm conditions and UV disinfection	Utilises proprietary telemetry control package. Monitoring and maintenance by public works staff.

Five of the case study sites had remote monitoring for all of the parameters listed in Table 5 (performance monitoring) in addition to a number of parameters listed in Table 3 (process monitoring). Another site had the capability to remotely monitor a large number of performance and process parameters, but chose not to do so. The experience of the manufacturer of this particular wastewater system was that, whilst engineers frequently requested state of the art remote monitoring and telemetry options, system operators have confirmed that they do not often use this and that the preference is for a simple auto dialler to notify them in case of alarm conditions. In order to satisfy the market, there is a package available which can be tailored specifically to the client's needs with a range of parameters that can be monitored. One of the other sites monitored only two parameters remotely and the two remaining sites had no remote monitoring enabled beyond alarm conditions.

4.10. Ability of equipment to interface with telemetry systems

The ability of equipment to interface with telemetry systems to allow remote monitoring is an important consideration. The literature suggested that in most situations it would be possible to interface equipment successfully; however our practical experience has been that unless manufacturers are involved from an early stage this is not always the case. Attempting to connect telemetry to allow remote monitoring of existing equipment that has not been specifically designed or set up for remote monitoring has proven to be a challenge on a number of other projects in the past and therefore we would recommend against doing this without professional assistance.

For the case studies investigated, all of the monitoring and control equipment installed had been carefully sourced to ensure compatibility with the telemetry setup as well as the other components and sensors. No sites reported any problems or faults with interfacing between equipment and telemetry. Given that remote monitoring requirements had been included at the design phase for many of these case study sites, this was not surprising. In addition, most case study participants worked with manufacturers and sales representatives to ensure that the equipment would meet their requirements.

4.11. Problems/issues experienced at the case study sites

Almost all of the case study sites reported some initial problems whilst the treatment plant was being commissioned or in the initial stages of operation. These problems varied in size and nature.

One issue involved air bubbles passing through the particle counter and triggering alarms. This problem was solved by modifying the sample tubing to dispel air bubbles prior to the particle counter. Another site reported a design fault had allowed backflow of chlorinated water during commissioning, which corroded the stainless steel UV sterilising chamber that subsequently had to be replaced. The design of this section of the treatment plant was modified to ensure this could not happen in the future.

Other problems experienced included issues with chlorination. The plant at one site had been designed to work with chlorine tablets, but once operational it was found that the chlorine tablets were too hard and not providing enough chlorination. A different type of tablet was trialled and the opposite problem occurred because the tablets were too soft and caused over chlorination. The chlorination system was then replaced with an online hypochlorite dosing unit.

One site reported problems with nuisance alarms indicating ‘out of parameter range’ for level transmitters in the chemical dosing tanks. The level transmitters were found to be located too close to the sides of the tank, causing an echo interference to occur and trigger the alarm.

In addition, some sites had experienced problems where unexpected and unusual wastes were put through the sewer and blocked the pumps. Improved screening processes have provided some resolution to these problems. Sewage backflow caused by blockages in sewer overflow lines during periods of low flow was reported at one site. This problem was overcome by pumping partially treated wastewater from the treatment plant back through the affected pipes on a daily basis to keep them clear.

Whilst none of the sites reported any problems with sensors or sensor failure, it should be noted that there are significant differences between brands and types of sensors in reliability, calibration and maintenance issues. The experience of the project team in the past has been that some sensors, particularly those at lower end of the price range, may have more reliability and failure issues and this is something that should be taken into consideration when selecting sensors. Problems and issues experienced at the case study sites can provide valuable information not only for this report but also in the future for other sites setting up wastewater recycling treatment plants to ensure that design complications and other simple mistakes are not repeated.

5. COST ANALYSIS

The costs of installing small scale wastewater treatment systems can vary significantly depending on the type and volume of wastewater that is to be treated along with the end use of the recycled water. Small scale household systems that supply treated water with potential for human exposure typically retail for $10,000 - $15,000.

On a larger scale, systems to treat volumes of water from a block of apartments or an office building are substantially more expensive. The information collected from the case studies shows that many of these systems cost in excess of $500,000 to design and build, which does not include ongoing maintenance costs.

There are a number of components that make up maintenance costs. The main ones include labour, consumables (including reagents), hardware and software (new sensors, upgrades to programs which operate items of equipment including the PLC), and laboratory costs associated with the regular testing required.

Labour costs can vary significantly depending on how well the system is operating. As an example, several of the sites investigated had an operator on site equating to between half and one day full time per week. However, this time factor can increase significantly if there are problems at the site which require an operator to attend (e.g. due to alarm conditions).

Further questioning about staffing and labour identified that the aim at some of the sites was to decrease on-site staff time even further without compromising the treatment plant operation.

The cost of consumables will vary depending on the treatment process being used. Typical consumables will involve disinfection reagents (e.g. chlorine) and calibration and testing reagents for both the online sensors and any handheld instruments. Other operating costs would mainly be attributed to replacement sensors and UV lamps where relevant.

Hardware costs may be included in the initial design and building of the treatment system and would typically include the remote monitoring and telemetry, and the main computer system and PLC. Software costs would be mainly attributed to occasional costs associated with upgrades to programs which run equipment. Sensor packages costing between $AUD 15,000 - 30,000 were commonly reported, which included interfacing and all software and hardware components.

Further costs are associated with any regular testing, and depend on the level of sampling required. This may be directly affected by the monitoring requirements of the relevant authority responsible for the area in which the treatment plant is located.

Table 8 below provides estimated costs for small scale wastewater treatment systems based on the components outlined above. The information provided in the table was compiled from the case study sites along with additional information from manufacturers and suppliers.

Table 8: Estimated costs for small scale recycling systems

Parameter	**Estimated costs**
Capital items	$200,000 +
Labour*	½ – 2 days per week
Consumables^ (including disinfection and calibration reagents, disposable test strips)	$2500 - $3000
Hardware (including PLC)	Up to $50,000
Sensor packages (including necessary software, hardware and interfacing)	$15,000 - $30,000
Replacement sensors	$1500 - $3000 each
Replacement UV lamps	$2000 +
Replacement parts (including pump parts, pump tubing, electrolytes/parts for probes)	$1000 - $2000
Ongoing verification testing (including laboratory testing)	$3500 – $7500
Handheld instruments used for calibration of sensors	$ 3000 - $10,000

*based on time required for maintenance and calibration of the system. This does not include additional time that may be required if problems arise at the site for which an operator is required to attend. Labour may also take the form of a maintenance contract with an external service provider.

^based on a treatment capacity of 30 KL/day. Costs of consumables will increase as the volume of wastewater treated increases.

Major capital items, hardware, sensors and handheld instruments are included in the initial upfront costs, although it should be understood that there can be additional costs associated with these items for upgrades and replacements in future years. Labour, consumables, replacement parts and ongoing verification testing are current annual costs. Labour has been expressed in terms of time required as the actual costs can vary significantly depending on the skill level of the staff involved and between companies. In addition some sites rely on volunteers who are not paid at all.

6. RECOMMENDATIONS

This project has identified a number of recommendations that could improve the ongoing process and performance monitoring of small scale wastewater recycling systems, including:

- Regular maintenance and calibration of sensors, probes and other equipment
- Correct sensor calibration procedures
- Using quality (purpose designed and manufacturer approved) sensors and equipment
- Implementing a monitoring regime appropriate for the intended end use of the treated water
- Connecting alarms to CCP parameters and enabling automatic shut down of the system if CCPs are breached
- Use of remote monitoring to allow treatment systems to be regularly checked by service provider or other responsible entities.
- Continuous collection and regular analysis of data from online sensors
- Further investigation into measuring UV transmissivity and the costs involved
- Ensuring adequate HSE procedures and policies are in place to protect volunteers and non-skilled staff involved in maintenance of treatment systems.

Further details for each of these recommendations are outlined below.

Regular maintenance and calibration of sensors plays an important role in reliably monitoring the ongoing performance of small scale systems. Many of the case studies investigated had a routine schedule for calibration and maintenance of sensors and other equipment. Whilst regular maintenance and calibration is readily implemented for larger systems that have trained operators to oversee and monitor the treatment system, this may present more of a challenge for systems at individual household scales and small neighbourhood plants. Sensor and equipment maintenance should be carried out on a monthly basis as the minimum. The calibration requirements provided by manufacturers should be adhered to, but in general, sensors and probes should be calibrated no less than once every 3 months. It is also good practice to compare sensor readings to those from handheld meters or laboratory results on a weekly basis.

Correct calibration of sensors and comparing the results to a reliable, calibrated portable instrument is very important. Whilst sensors can appear to be giving correct readings, this can only be verified by comparing them to another instrument over a range of expected values. Regular grab samples outside of the calibration schedule should also be analysed and compared to online data to ensure the calibration remains valid. The frequency of such grab samples should be at least monthly. Regular verification monitoring is very important for small scale systems to ensure water quality standards are being met. This is important for both human health and environmental reasons. A simple microbiological analysis for an appropriate target organism in the treated water should be undertaken weekly or fortnightly to ensure adequate water quality for human health purposes. More extensive monitoring including other microbiological parameters and chemical and metals analysis should be carried out every 6 months.

This research also identified the importance of using quality sensors and equipment designed for the purpose and situation. Sensors designed for clean water should not be used in wastewater environments and then expected to perform as well as a sensor designed for that application unless so advised by the manufacturer. Quality is also a very important factor, where sensors and associated equipment can range from several hundred dollars or less to thousands of dollars for one sensor. Whilst at the higher end of the scale the cost may be significant, especially for a very small or individual household system, the value of employing high quality equipment should be carefully considered. The results from the case studies show that whilst the sensor packages employed cost a significant amount, there were very few sensor failures or problems. Our experience is that cheaper sensors used in other wastewater projects have deteriorated rapidly in the first several months and had ongoing issues with calibration, sensitivity and reliability.

The importance of selecting a monitoring regime appropriate to the intended end use of the water was also identified. This approach allows some flexibility in determining a suitable level of rigour for the monitoring program. For example, recycled water with the potential for direct human contact requires a more stringent approach to be adopted.

UV transmissivity has been identified by some regulatory authorities as an important parameter to provide an indication of the effectiveness of UV disinfection. However, it was found that UV transmissivity was not being monitored at all case study sites, with cost being cited as the biggest barrier. This may need to be explored further to promote the importance of monitoring UV transmissivity as well as lamp intensity. This could be of particular importance for systems that produce treated effluent where the end use involves direct human contact. For systems using UV disinfection, the specifications of the initial UV lamps used during commissioning and accreditation should be recorded to ensure that replacement lamps meet the same specifications.

The ability to connect critical control point parameters to alarms that can automatically shut down a system in event of a water quality breach or other fault adds an extra level of control and should be considered for systems of any size. Further investigation would be required to determine the viability of implementing such control measures for particular systems. Treatment systems where there is potential for human contact with the recycled water would be the most likely to benefit from this extra level of control. In particular alarms and automatic shut down linked to the disinfection process should be considered for all systems.

Remote monitoring and telemetry is best budgeted for and included at the commencement of any new project. This ensures that the instrumentation required can be selected to interface with the necessary monitoring and telemetry equipment. Adding remote monitoring and telemetry at a later stage can then be done relatively easily if the appropriate inclusions have been made in the early stages of designing and building new treatment systems. Including the ability to allow remote monitoring should be considered for systems of any size.

It was found that most of the sites collected and analysed data from online sensors at regular intervals. At least one site conducted regular monthly meetings at which the data was discussed to determine and establish trends. Whilst collecting data is usually not difficult, knowing which data to collect and how frequently can present a challenge. Analysing and interpreting the data correctly and determining and establishing trends can provide valuable information about how well the system is performing, as well as providing an indication of any potential problems and failures. However, it may be necessary to seek expert advice in relation to collecting and analysing data from online sensors in terms of frequency of data collection and how to best analyse and interpret the information obtained. For best practice performance monitoring continuous data collection and weekly analysis of the data is recommended, as this allows any unusual trends and patterns that may indicate potential sensor problems to be detected.

With the many and rapid advances in the telecommunications industry the possibility of options such as using sensor networks both within a treatment system as well as more broadly to network systems within a neighbourhood or even on a larger scale are quickly becoming a reality. This would allow more options in terms of how small scale systems are managed, monitored and maintained. For example, a centralised facility monitoring and maintaining a large number of systems may reduce costs and also provide an extra level of control, as the systems would be looked after by suitably qualified personnel to ensure that they are operating correctly and producing recycled water of the quality expected.

There are also many advances being made with monitoring technologies and techniques. It is important to consider new and emerging techniques and technologies as they become available as this will ensure that best practice performance monitoring continues to move forward and improve. To this end, an annual review of the literature as well as keeping in contact with service providers and manufacturers of sensors and other equipment suppliers is recommended.

Sites with small scale recycled water systems where community volunteers or other non-skilled staff are enlisted to assist with day to day monitoring and operations (such as at eco-housing/villages) need to ensure that they have an appropriate HS&E procedure and policy in place to protect those volunteers and staff. In addition a training program should be developed and relevant training logs and documents retained. Volunteers and non-skilled staff should not be expected to carry out tasks for which they are not adequately trained. The responsibility of ongoing maintenance should remain with the service provider or other responsible entity.

A summary of the best practice and performance monitoring steps for small scale wastewater recycling systems is presented in Appendix 1 (Table 9).

7. CONCLUSIONS

This project combined a survey of the literature along with small scale case studies to obtain a good representation of both theoretical and practical information. The literature review identified a number of process and performance parameters that could be used to monitor small scale systems for ongoing performance. The process parameters identified include water level, flow rate, pressure, pump function, and other on/off switches; as well as turbidity and UV intensity. Process control strategies were also considered as they are closely linked to process monitoring and include failure of system components. Performance monitoring parameters that were identified in the literature include online methods for residual chlorine (free and total), pH, DO, EC, turbidity, SS, ORP, temperature and particle counts; as well as routine grab sampling for bacteria, viruses and protozoa counts. The case study sites were found to be monitoring many of the process and performance parameters identified in the literature.

The information collected has allowed a number of current best practice and emerging monitoring approaches to be identified, such as the use of networks and remote control to centrally monitor a number of systems in the future. The monitoring approaches for systems that are not staffed on a continuous basis need to be practical as well as robust and reliable. The approaches identified and described in this report are all used or intended for use with small scale treatment systems, with many of them being used successfully at the case study sites.

A Hazard Analysis Critical Control Point (HACCP) risk management methodology is essential to identify hazards in different stages of the treatment system and develop appropriate risk management strategies. HACCP plans are not a new concept and all treatment systems regardless of size should have one.

Online monitoring has also been identified as an essential component of a best practice monitoring approach. The monitoring approaches outlined in this report fall into two main categories; monitoring to identify a reduction in treatment plant performance, or preventative monitoring to avoid a reduction in treatment plant performance. Online monitoring of certain critical control point parameters can definitely identify a reduction in treatment plant performance. Most parameters can be adjusted to operate within a narrow range and trigger an alarm or a plant shutdown in the event of the parameter moving out of the preset range. Many of the process monitoring approaches could be considered to be more preventative measures rather than being able to identify a direct reduction in treatment plant performance (e.g. identifying problems with flow, pressure, pump function or failure of system components). Process monitoring allows problems to be identified before they cause a reduction in the treatment plant performance and hence treated water quality. For this reason it is a very valuable component of performance monitoring.

Collecting and regularly analysing data from sensors and other outputs allows changes and any irregularities in the system to be detected early and monitored or investigated further if required before a failure can occur.

The importance of a regular maintenance and calibration schedule should not be underestimated, as this will also allow detection of issues with sensors and other equipment such as pumps and valves. Regular maintenance and calibration can also detect problems such as sensor drift and a slowdown in response time.

This research highlighted the importance of investing in good quality equipment. Several more expensive sensors were found to last longer and suffer less reliability and accuracy issues than cheaper versions. Whilst the initial outlay for these can be significant, the case study sites were able to demonstrate the value in investing in the more expensive options as they reported very few sensor failures or replacements.

An additional best practice performance monitoring approach also identified was to ensure the sensors and equipment are designed for the purpose for which they are employed, or approved by the manufacturer for that purpose (i.e. sensors designed to operate in clean water conditions should not be employed in the wastewater side of the treatment process and expected to perform well in that environment for extended periods of time).

The ability to include remote monitoring is emerging as a best practice monitoring approach. As small scale systems are not continuously staffed, enabling a skilled trained operator to remotely check the system on a regular basis ensures that any issues can be detected and resolved rapidly.

Appointing one person as responsible for attending to alarms and problems has been implemented by a number of the case study sites. It has proved to be a valuable strategy as it eliminates any confusion over who needs to respond to any problems.

Some of the weaknesses of the monitoring approaches described in this report are that they work well when all the procedures in the operation and maintenance manuals and verification schedules and plans are followed correctly, but have the potential to fail if procedures and schedules are not adhered to. For example, regular calibration and maintenance schedules are only effective if they are actually undertaken. Similarly for treatment systems that have alarms, these are only effective when someone actually investigates and rectifies the cause of an alarm rather than to simply reset and re-start the system. Many systems allow easy data collection but this is only useful if the data is properly analysed to obtain meaningful results over a reasonable period of time and then compared to current data to observe differences in trends.

The costs associated with monitoring will vary depending on the approaches chosen. However, the biggest costs in most situations would be associated with the initial setup of the monitoring system, including purchasing the necessary equipment. Simple online monitoring equipment including quality sensors and alarms on critical control point parameters would be expected to start from several thousand dollars for monitoring one or two parameters. Adding the ability for the treatment system to automatically shut down in case of a significant alarm would be expected to add several thousand dollars and increase from there depending on the size of the system, number of parameters and the level of monitoring required.

The results from this research showed that much of the information presented in the literature in relation to monitoring technologies and techniques is being used in representative case study site environments. The results from the case study sites showed that small scale wastewater treatment systems can be successfully maintained and monitored. Advances in telecommunications will also lead to better remote monitoring and telemetry abilities further enhancing the control of systems remotely.

Some further research is recommended to address the issues raised concerning the benefit of monitoring UV transmissivity, as well as investigating the feasibility of using online and remote monitoring for even the smallest systems (i.e. individual household size). In addition, the use of monitoring networks should be explored, as this could present a potential option for monitoring and maintaining a large number of systems through a centralised facility.

8. GLOSSARY OF TERMS

Term	Description
AGWR	Australian Guidelines for Water Recycling. Guidelines: Managing health and environmental risks (Phase 1).
BOD	Biological Oxygen Demand - the amount of oxygen consumed by chemical processes and microorganisms to break down organic matter in water over a five-day period, measured in milligrams per litre (mg/L).
Blackwater	All wastewater including that from toilets and kitchen sinks.
CCP	Critical Control Point.
COD	Chemical Oxygen Demand - the milligrams of oxygen required to chemically oxidize the organic contaminants in one litre of wastewater.
Decentralised system	Decentralised systems involve the collection, treatment and use of wastewater at different spatial scales, from individual homes, clusters of homes to urban communities.
DO	Dissolved oxygen - the oxygen dissolved in water, wastewater, or other liquid. DO is measured in milligrams per litre.
EC	Electrical Conductivity.
Free chlorine residual	Residual concentration of chlorine available for disinfection after reactions with organic material, metals and other compounds present in water.
Greywater	Wastewater collected from the bathroom, laundry and sometimes the kitchen but excludes wastewater from toilets.
Guidelines for Validating Treatment Processes for Pathogen Reduction – Victoria	Guidelines produced by the Department of Health in relation to pathogen reduction for treatment processes.
HACCP	Hazard Analysis and Critical Control Points.
HAZOP	Hazard and Operability study.
Inline Monitoring	Probes are placed directly into the flow of the sample to be analysed.
Inorganic ions	Relating or belonging to the class of compounds that do not have a carbon basis (i.e. salts, acids).
MBR	Membrane Bioreactor - commonly used in wastewater treatment plants.
ML	Mixed Liquor - the mixture of activated sludge, wastewater, and oxygen, wherein biological assimilation occurs.
MLSS	Mixed Liquor Suspended Solids - the milligrams of suspended solids per litre of mixed liquor that is combustible at 550℃. An estimate of the quantity of MLSS to be wasted from the aeration tank of an extended aeration plant may be determined by the rate of settling and centrifuge tests on the sludge solids.
Online Monitoring	Typically involves extracting some of the sample from the main flow for analysis by an online instrument after which the sample may be discarded or pumped back into the main flow.
Organic load indicators	Indicators which can be used to determine the

	amount of organic material.
ORP	Oxidation reduction potential.
Physicochemical parameters	Parameters that are measured to determine information about water quality relating to physical chemistry or both physics and chemistry.
PCR	Polymerase chain reaction – a
PeCOD	Photoelectrochemical chemical oxygen demand
pH	Measure of acidity or basicity of an aqueous solution.
Project Champion	The main person responsible for overseeing the project mainly during development.
Protozoan parasites	Protozoan parasites are protozoa that have adapted to invade and live in cells and tissues of other organisms and can make humans and animal very ill.
Small scale	For the purposes of this project, small scale refers to wastewater treatment plants that are not staffed on a full time basis.
SME	Small to Medium Enterprise.
SWF	Smart Water Fund.
SS	Suspended Solids - small solid particles that remain in suspension in water and is often used as a water quality indicator along with other parameters.
Telemetry	Telemetry is the infrastructure and components required to undertake remote monitoring.
Turbidity	The cloudy appearance of water that is an indication of fine solids suspended in the water, measured by a light penetration test and expressed in nephelometric turbidity units (NTU).

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10. APPENDIX 1

Table 9: Best practice and performance monitoring steps for small scale wastewater recycling systems

No.	Parameters	Recommended Best Practice Process and Performance Monitoring
1	Conduct Risk assessments to prevent design complications.	Use HAZOP and other risk assessment tools.
2	Develop appropriate HACCP risk assessment for individual small scale wastewater recycling system.	Use HACCP risk management assessments and strategies.
3	Identify optimum location for sensors.	HACCP plan may assist with identifying optimum location for some sensors.
4	Identify suitable quality equipment (e.g. sensors) for treatment train.	Ensure correct selection of sensors for the location in which they are to be placed.
5	Identify CCP parameters within the treatment system.	Consider implementing alarm and automatic shut down for these parameters.
6	Test (pre-commission) prior to treatment plant operation.	Check sensors and other equipment in pre-commissioning stage.
7	Develop procedures/manuals/steps to be carried out during plant failure.	Use HACCP plan and develop procedures/manuals and recording procedures/logs for plant failures. Plan should include response time within which different failures must be addressed.
8	Identify maintenance (preventative and corrective) and calibration schedule of sensors and other equipment.	Develop schedules, procedures and record logs for maintenance and calibration of sensors and other equipment. Include daily, weekly, monthly, quarterly and annual requirements. As a minimum, maintenance and calibration procedures outlined by manufacturers of sensors and other equipment must be followed. Ensure reliable, calibrated portable instruments are available for calibration.
9	Identify types of monitoring systems (i.e. remote monitoring, data collection, online monitoring, inline monitoring, and lab analysis).	Ensure that monitoring requirements are considered during the design/building phase of new treatment systems to ensure smooth integration of monitoring equipment. CCPs parameters should have remote monitoring and alarm capability.
10	Identify statistical techniques required for analysis of data to ensure the required information can be easily obtained.	Data should be monitored daily and analysed weekly to determine any trends or unusual patterns within the treatment system. Procedures should be developed for requirements for handling trends or unusual data and detailed records produced.
11	Determine frequency of sampling for verification monitoring.	Consider end use of recycled water, license requirements and any other regulatory or council requirements.
12	HS&E procedures.	Develop HS&E procedures for staff working at the site. Ensure that volunteers and non-skilled staff are not expected to carry out tasks for which they are not adequately trained. Keep records of training logs.

Contact Us

Phone: 1300 363 400
+61 3 9545 2176

Email: enquiries@csiro.au

Web: www.csiro.au

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