Monitoring Treated Wastewater Ocean Outfall Pipelines and Seawater Intakes Using Pathogen Sensors and other Remote Monitoring Methods

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Abstract

This research focuses on identifying technologies in the current market suitable for continuous online monitoring of pathogens at treated wastewater ocean outfalls and seawater desalination plant intakes. Benefits would include early warning of an increase in pathogen levels in treated wastewater being discharged to the ocean and detection of changes in pathogen levels at seawater desalination plant intakes. An example where this would apply is at the upcoming Alkimos seawater desalination plant, where the seawater intake will be approximately 2 km away from the existing Alkimos treated wastewater ocean outfall. Continuous monitoring would aid operations at wastewater treatment plants and seawater desalination plants and support compliance with environmental and health requirements.

The research commenced with a market scan and screening to identify a shortlist of suitable technologies (instruments) from a pool of commercially available options. The preferred technology, the ColiMinder, is being used in pilot trials to verify its capabilities and performance relevant to Water Corporation's operations. Preliminary results of pilot trials have shown good correlations between the conventional methods and the technology trialled.

1. Introduction

1.1 Project Background and Current Environment

Water Corporation is planning to establish its third seawater desalination plant at Alkimos, to be operational by 2028. The Alkimos seawater desalination plant (ASDP) will be taking in seawater through an intake located approximately 2 km from the existing Alkimos treated wastewater (TWW) ocean outfall. The proximity of the TWW outfall to the ASDP intake/feedwater is acceptable but presents a potential operational risk for Water Corporation, requiring active management. Modelling the fate of the TWW outfall plume in relation to the ASDP intake indicated some diluted TWW mixing into the feedwater and a potential challenge to the ASDP intake water quality in the event of wastewater treatment process deviations (DHI, 2023). Whilst ASDP will have high levels of treatment, there is a need to understand the potential risk during operations by continuously monitoring pathogen levels at the ASDP intake and possibly also in the TWW discharge. The permissible pathogen levels at the seawater intake are summarised in Table 1 (Water Corporation, 2021):

Table 1 ASDP Seawater Intake Performance Criteria (Water Corporation, 2021)

Seawater Intake Performance Criteria		
Pathogen	**Level**	**Description**
Thermotolerant Coliforms (TTC)	<20 CFU/100mL	TTC <20 CFU/100mL for 95% of the time, calculated over a period of no more than one week, and not to exceed 2,000 CFU/100mL at any time
Enterococci	<4 MPN/100mL	<4 MPN/100mL for 95% of the time, calculated over a period of no more than one week, and not to exceed 400 MPN/100mL at any time

The TWW discharged from all ocean outfalls needs to be monitored for pathogens under the guidelines specified by the Department of Water and Environmental Regulation (Water Corporation, 2022) Pathogen levels are currently monitored via the collection of seawater 'grab samples' at distances around each ocean outfall over the December to March period and via weekly laboratory testing of TWW samples from the treatment plants prior to ocean discharge. Continuous, year-round inline monitoring of pathogens in the TWW prior to discharge would increase Water Corporation's understanding of public health and environmental risks. The estimated levels of thermotolerant coliforms (TTC) and Enterococci discharged under various Wastewater Treatment Plant (WWTP) operating conditions and treatment processes are summarised in Table 2 (Water Corporation, 2021):

Table 2 TWW performance criteria (Water Corporation, 2021), membrane aerated biofilm reactor (MABR), membrane bioreactor (MBR)

Wastewater Treatment Process	Pathogen	Normal operating conditions	Mild off-spec operating conditions	Extreme off-spec operating conditions
Oxi-Ditch & Oxi-Ditch/MABR	TTC (CFU/100mL)	100,000	10,000,000	55,000,000
MBR		<10	1,000	N/A
Oxi-Ditch & Oxi-Ditch/MABR	Enterococci (MPN/100mL)	20,000	200,000	1,700,000
MBR		<10	200	N/A

The current measurement technique takes samples and sends them to a laboratory for analysis of prospective pathogens. Pathogen levels are determined following the National Association of Testing Authorities (NATA) guidelines requiring culturing to determine pathogen counts. Results are typically available 48-72 hours from the time of sample delivery.

1.2 Project Scope

The scope of this project was to analyse the current technologies available for online pathogen monitoring and identify one that meets the selection criterion. Water Corporation aims to achieve the following objectives:

- Support proactive response to managing the environmental impact of TWW discharge in the event of deviations in TWW quality. The response is based on the TWW performance criteria specific to each WWTP.
- Support seawater desalination water safety plans through early warning of elevated levels of pathogens in the feedwater and enabling restart of water production following a shutdown due to feedwater quality issues (based on the Seawater Intake Performance Criteria specific to each SDP).
- Potentially reduce the reliance on marine grab sampling programs over time, which could reduce safety risks associated with marine sampling and reduce the cost of the grab sampling programs.

2. Technology Selection and Validation Process

2.1. Technology Market Scan and Screening

The technology scan included reviewing catalogues, case studies and application notes from the supplier/manufacturer websites. An Excel workbook was prepared containing a list of prospective technologies with each technology going through a preliminary, secondary, and final screening. The Figure 1 below shows a list of technologies researched and their working principles:

Sr. No.	Technology Name	Technology Type	Working Principle
1	ColiMinder	Reagent Based Flourescent Spectroscopy	Measures enzymatic activity by detecting the flouresence of the accumulated reaction product
2	Tecta		
3	BACT control		
4	Aqua Bio		
5	Colifast Calm		
6	V bact Microbial scanner	Microscopic Imaging	Intelligent microscope based technology, capable of identifying Pathogenic and Non-Pathogenic Viable Bacteria.
7	Aqua Track		
8	ALVIM Biofilm	Biofilm Measurement	Detects Biofilm growth on an inline Stainless steel electrode by measuring variation in the Electric signals passed through it.
9	BioGeorge		
10	Bactosense	Flow Cytometry	Optical detection of pretreated sample Pathogens. The technology involves photomultiplier tubes
11	Bacti-station	Tryptophan Flouresence Detection	Measurement of flouresence due to Tryptophanase, which can be correlated to measure E. *Coli* levels
12	Aqua Scope	FISH (Flouresence In situ Hybridisation)	Cultivation using filter cytometry followed by flouresence detection of pretreated sample using Automatic Image Analysis.
13	EZ ATP	ATP (Adinosine Tri Phosphate) Flouresence Detection	Detection of luminescence generated by Adenosine Tri Phosphate (ATP) (an energy currency for all living organisms) by means of a chemical reaction reaction using Luciferin and Luciferase enzyme.

Figure 1 Technology List and their Working Principles

The technologies were compared with a set of criteria derived from various literary sources and application specific parameters. A screening process was developed to filter out the relevant technology using categorised preliminary, secondary and final screening. The preliminary screening focused on key monitoring features, secondary screening was based on viable bacteria monitored and the final screening was developed considering the Water Corporation operational requirements.

After a rigorous process, The ColiMinder from Vienna Water Monitoring Solutions was shortlisted for pilot trials. The ColiMinder is a fully automated pathogen monitoring technology with the capability of measuring *E. coli* (as a proxy for TTC), Enterococci and Total microbial activity. Continuous, online and remote monitoring of data is possible through a hand held device/PC connected to the internet. The ability of the technology to provide results in high background salinity makes it suitable for seawater applications. Real time measurement of pathogens is possible as the measurement cycle lasts for 15 minutes only.

2.2. Trial Validation of Technology

The objectives of the trial were to test the accuracy and consistency of the selected instrument (ColiMinder) by comparing the results of the online pathogen monitoring technology (alternate technology) with the reference technology (NATA accredited laboratory sampling), and to understand how the technology could be implemented into Water Corporation's operations. The trial validation was performed sequentially in 3 steps outlined below:

Step 1: Source Water Assembly

Screened seawater (devoid of any large particles) was sourced from the Perth seawater desalination plant in Kwinana. Treated wastewater and primary effluent were sourced from the Subiaco Water Resource Recovery Facility adjacent to the Water Research and Innovation Precinct (WRIP), where the trial was conducted.

Step 2: Sample Preparation Process

Samples were prepared according to the combinations outlined in Table 3. TWW samples were spiked with increasing levels of primary effluent and seawater samples were spiked with increasing levels of TWW. The purpose of the samples design was to test the performance of the ColiMinder for a large range of pathogen concentrations, replicating the extent of what could be encountered in operational scenarios.

Table 3 Sample Preparation Process

Dilution Levels	Sample ID	Treated Wastewater Volume (litres)	Primary Effluent Volume (litres)	Proportion of Primary Effluent
Treated Wastewater (*E. coli* and Enterococci Testing)				
Dilution Level 1	WW-1-X*	5	0	0%
Dilution Level 2	WW-2-X*	4.5	0.5	10%
Dilution Level 3	WW-3-X*	4	1	20%
Dilution Level 4	WW-4-X*	3.5	1.5	30%
Dilution Level 5	WW-5-X*	3	2	40%
Dilution Level 6	WW-6-X*	2.5	2.5	50%
Screened Seawater (*E. coli* and Enterococci Testing)				
Dilution Levels	**Sample ID**	**Screened Seawater Volume (litres)**	**Treated Wastewater Volume (litres)**	**Proportion of TWW**
Dilution Level 1	SW-1-X*	5	0	0%
Dilution Level 2	SW-2-X*	4.5	0.5	10%
Dilution Level 3	SW-3-X*	4	1	20%
Dilution Level 4	SW-4-X*	3.5	1.5	30%
Dilution Level 5	SW-5-X*	3	2	40%
Dilution Level 6	SW-6-X*	2.5	2.5	50%

* X=1 for *E. coli* and X=2 for Enterococci

Step 3: Trial Setup and Execution

1. The samples were prepared in 5 litre containers as per the levels recorded in Table 3. Trial setup was on a bench scale and can be seen diagrammatically in Figure 2 below.

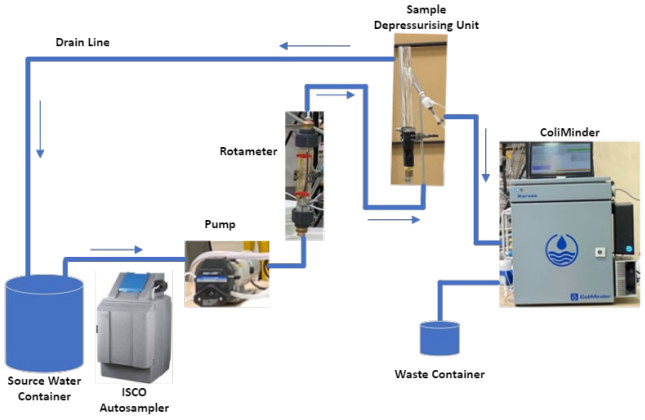

Figure 2 ColiMinder Trial Setup

2. The ColiMinder was set to sample at pre-defined intervals and simultaneous manual samples were taken within a few moments of the automatic sampling done by the ColiMinder. The manually collected samples were chilled in the refrigerated compartment of an ISCO autosampler before being taken to the Pathwest laboratory for testing (Pathwest is the laboratory Water Corporation uses for existing pathogen testing procedures).

3. Three samples for each dilution level were taken using both the ColiMinder and manual sampling to enable triplicate laboratory testing and provide enough data points to undertake statistical analysis of the results.

3. Results and Discussion

The results showed a high correlation between the parameters of interest, these were; 1) ColiMinder results and spiked effluent concentrations, and 2) ColiMinder results and laboratory results. As per Tables 1 and 2, Enterococci and TTC are the key monitoring parameters for maintaining the performance criteria of the TWW outfall and seawater intake. Since the ColiMinder measures *E. coli*, the strong correlation between *E. coli* and TTC will be verified in this research and documented in the final report. A tabular and graphical representation has been shown below (Table 4 and Figure 3) for *E. coli* testing on TWW spiked with primary effluent:

Table 4 Trial Results for *E. coli* in TWW

Sample ID	Treated Wastewater Volume (litres)	Primary Effluent Volume (litres)	Proportion of Primary Effluent	ColiMinder Results in mMFU/100mL Avg.	Pathwest Results in CFU/100mL Avg.	ColiMinder Transmission %
WW-1-1	5	0	0%	3,258.14	28,000.0	14.48
WW-2-1	4.5	0.5	10%	7,219.65	58,000.0	7.90
WW-3-1	4	1	20%	10,308.02	107,333.3	5.51
WW-4-1	3.5	1.5	30%	13,626.76	3,500,000.0	3.57
WW-5-1	3	2	40%	17,935.81	4,266,666.7	2.01
WW-6-1	2.5	2.5	50%	20,516.10	4,933,333.3	1.12

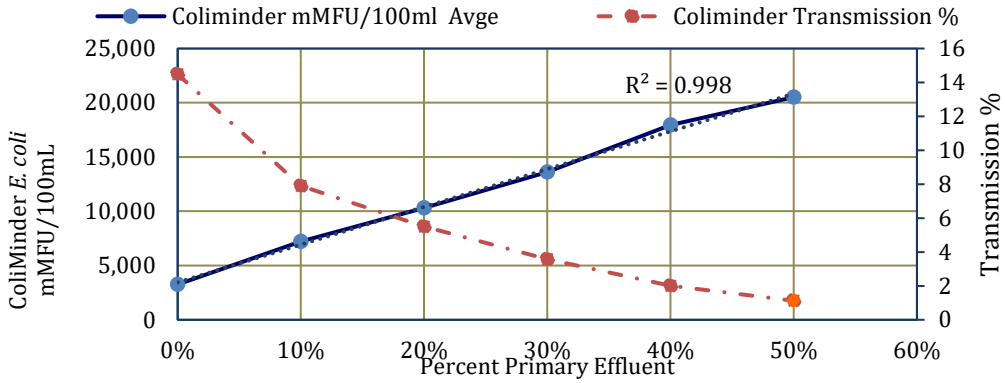

Figure 3 ColiMinder Results vs Percentage of Primary Effluent for *E. coli*

Each data point in the results graphs is an average of 3 sample results tested by the ColiMinder and the lab. The correlation between the ColiMinder results and sample dilutions of primary effluent is 99.8% (shown in Figure 3). The correlation between the ColiMinder and lab results is 92.8% (shown in Figure 4). Note here that the measurement units of the ColiMinder (Enzymatic Activity per Volume) and lab samples (Colony Forming Units per Volume) are different, hence it is useful to establish a correlation between the two. Details regarding the units for *E. coli* and Enterococci results from the ColiMinder will be outlined in the final report of this project. Figure 3 shows a decrease in transmission level of the light signals passing through the sample as the proportion of primary effluent increases, which is an intuitive result.

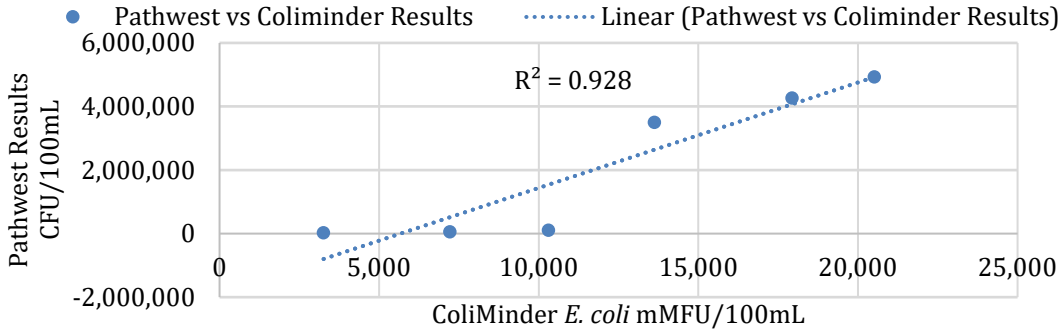

Figure 4 ColiMinder Results vs Pathwest Lab Results for *E. coli*

Further trials on screened seawater for *E. coli* has also produced similar results with a correlation of 99.5% for ColiMinder vs varying concentrations of TWW in seawater. A correlation of 96% was seen between the ColiMinder and lab results for the same. Trials are ongoing for Enterococci measurements using the sample preparation procedures as indicated in step 2 of section 2.2.

4. Conclusions and Future Work

Testing the ColiMinder on conditions that may be encountered in an operating environment was a primary objective achieved through these trials. The results have identified a strong correlation between the parameters of interest. Engagement with a range of stakeholders across Water Corporation indicated interest in using the ColiMinder in several operational settings. In addition to the proposed Alkimos WWTP and ASDP applications outlined in this report, there is potential to utilise the ColiMinder to assist with surface water source risk assessment, regional TWW reuse compliance and incident response. Water Corporation will continue to seek opportunities for research and development projects using the ColiMinder and possible field deployments.

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6. References

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