

An inline sensor to detect cross-connections between potable and recycled water systems in real-time

Milestone 3: Report

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1 Introduction

With the introduction of dual-reticulation schemes, a considerable number of water quality incidents have occurred due to cross-connections, misconnections and water system faults. Such schemes represent public health, reputational and public perception risks, which need to be managed efficiently. In conjunction with the Australian Water Recycling Centre of Excellence (AWRCOE), CSIRO are undertaking a project to develop an inline sensor that can detect cross-connections between potable and recycled water systems inside individual houses in real-time. This will enable close management of risks and help maintain consumer confidence in recycled water schemes.

Electrical conductivity (EC) has previously been demonstrated to be a good basis for cross-connection detection (O'Halloran et al., 2010), however in waters with unstable EC or where EC differences are negligible, an alternative indicator is desired. In this case, both UV and fluorescence have been shown to vary between potable and recycled water supplies, primarily due to the heightened levels of amino acids and proteins in recycled water, and their relatively low levels in potable water supply. The reverse, however, may be found where membrane technologies (i.e. reverse osmosis) are used to treat recycled water and therefore remove dissolved organic carbon to much lower levels than in the potable supply.

This project works towards making a universal cross-connections device that can utilise both UV/fluorescence and EC parameters for use within consumer premises. The device will compare water quality between the point of supply (e.g. smart water meter) and point of use (e.g. kitchen sink), and may utilise wireless communications from the smart water meter.

Previously we demonstrated to the Research Advisory Committee that by using a paired t-test to examine differences in the fluorescence, utilising multiple measurements at the point of consumption in the drinking water distribution system, it was possible to greatly improve the detection limits for monitoring contamination of recycled water (O'Halloran and Gould, 2013). Data contained in a publication from UNSW (Hambly et al, 2010) showed that fluorescence measurements could detect 45% contamination of recycled water in drinking water with a signal-to-noise ratio > 3 for more than 95% of individual random sample pairs. We also found that 10% contamination with recycled water was not often detected from fluorescence data using pairs (2 samples), however it was readily detected 99% of the time for 5 samples and was always detected using 10 samples, confirming with the t-test that replicates greatly improved the performance.

In earlier work (O'Halloran and Gould, 2013) it was also demonstrated that a paired t-test could also provide distinction of potable and recycled water based upon EC measurements. Potable and recycled water at a treatment plant (Site 1) were compared in order to test the limits of approach. Site 1 was chosen as there was large variability in recycled water's EC supplied to the distribution system and would thus prove to be the most challenging to detect a cross connection, as opposed to the data from two other sites where detection would be much simpler. It was demonstrated that testing the difference in water quality between the point of supply and point of consumption remained sensitive and was able to detect 10% contamination even with a large variability in recycled water composition.

Having established the validity of the paired t-test approach, we have set about developing a sensor system based on measuring the fluorescence emission of the recycled water.

As stated in the project description, inline sensors will be developed to provide improved detection of wastewater contamination from cross-connections with a target detection limit of 10% contamination with recycled water. Furthermore the inline sensors are being developed with the view of being affordable in-home devices, as opposed to expensive, analytical instruments.

With these objectives in mind, herein we report on the spectroscopic characterisation of recycled water samples from different treatment plants, and present a statistical analysis of recycled water fluorescence based on laboratory measurements. This forms the basis of the first affordable inline sensor for monitoring

cross-connections. The construction and performance of the first prototype is detailed and future needs for improved detection are discussed.

2 Characterisation of Recycled Water Samples

To determine the absorption and fluorescence properties of the recycled water across multiple sites, potable and recycled water samples were obtained from three project partners, and herein are labelled Site 1, Site 2 and Site 3. Recycled water from each of the sites underwent different treatment processes. For Site 1, the recycled water was subjected to ozone and biological media filtration coupled with ultraviolet and chlorine disinfection. For Site 2, firstly the recycled water was subjected to micro-filtration followed by UV disinfection and chlorination. Lastly for Site 3, a process of ultrafiltration followed by UV disinfection and chlorination was performed on the recycled water.

These samples were subsequently characterised by UV-vis absorption and by fluorescence spectrophotometry. Recycled water was mixed with recycled water to simulate different recycled water concentrations.

2.1 UV-vis characterisation

All absorption spectra were obtained using standard 1cm path length quartz cuvettes. Figure 1, Figure 2 and Figure 3 below show the absorbance spectra for different recycled water concentrations from the three sites. Although a linear relationship exists between the absorption maxima and the recycled water concentration, there are no absorption peaks occurring at the characteristic 254 nm wavelength. It should be noted that the 254 nm absorption band is typically a measure of the aromatic character of dissolved organic matter, and consequently aliphatic molecules, such as proteins and amino acids, may not appear in this band.

The samples were analysed several times, repeated with different UV-vis instruments and with different quartz cells, yet on each occasion the same observation was made. It appears that during the treatment processes these 254 nm absorbing compounds are either removed or broken down, consequently leaving no trace in the absorption spectra.

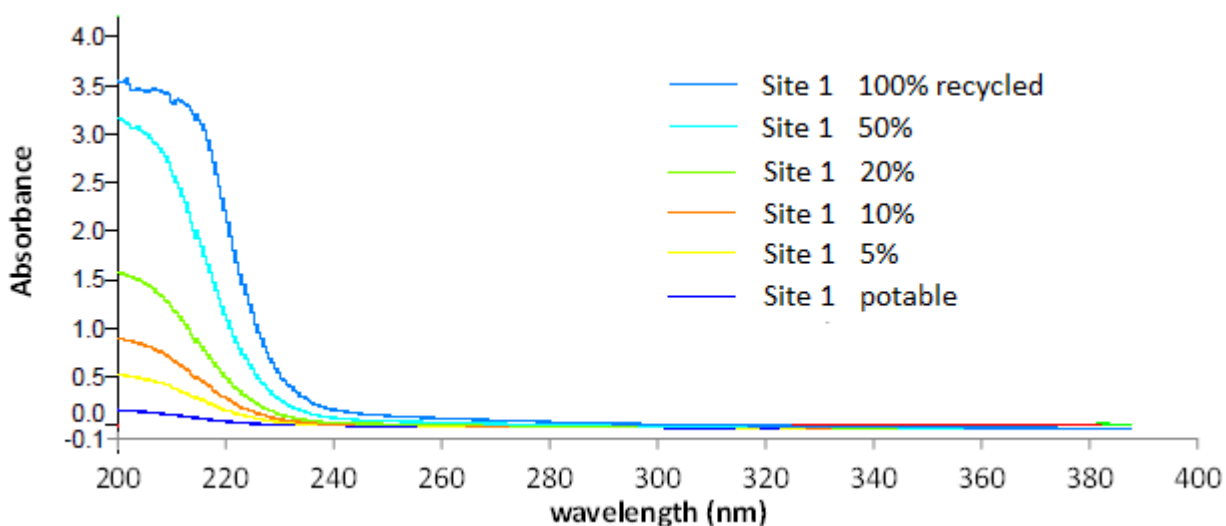


Figure 1: UV-vis absorbance spectra for different concentrations of recycled water from Site 1.

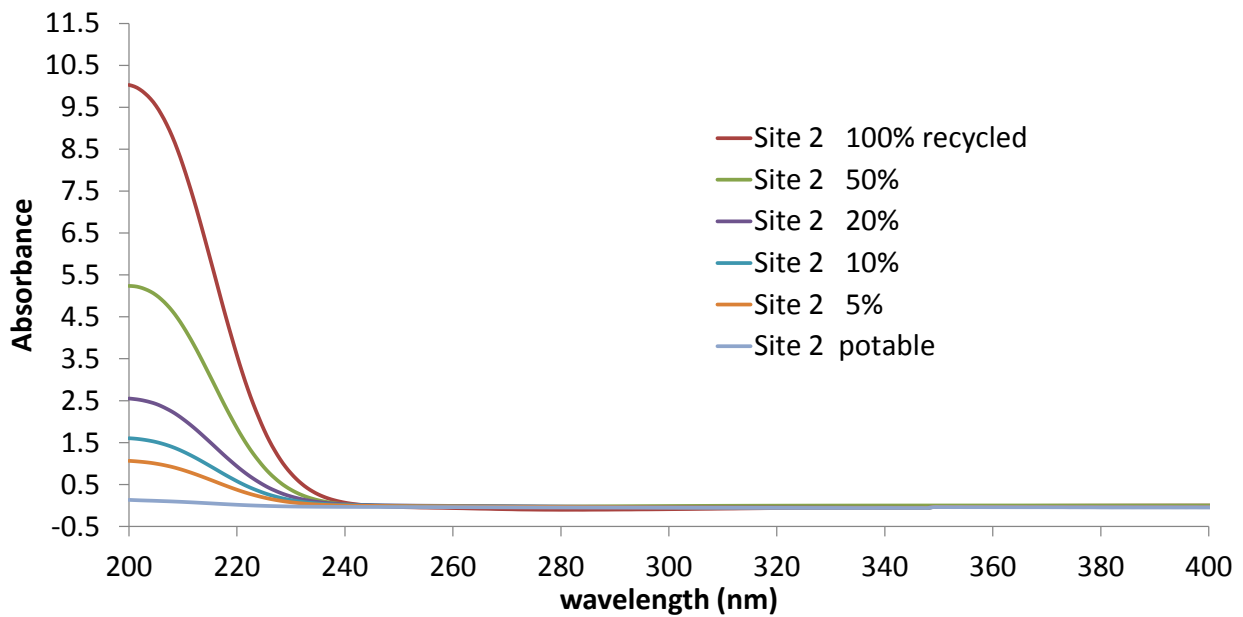


Figure 2: UV-vis absorbance spectra for different concentrations of recycled water from Site 2.

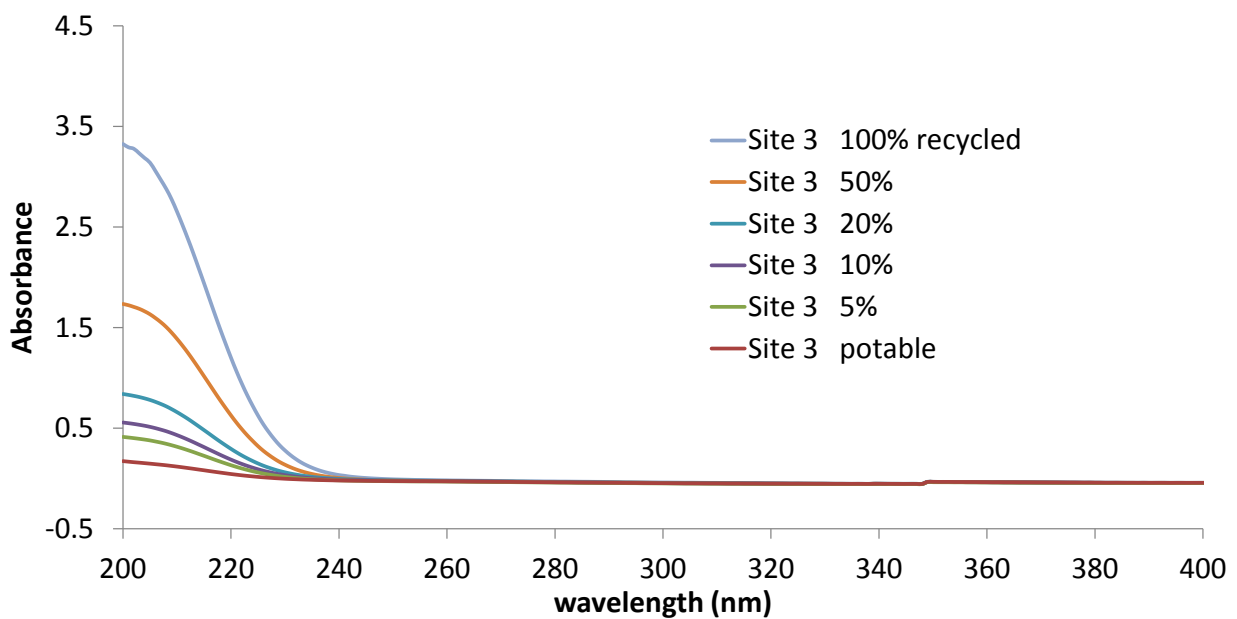


Figure 3: UV-vis absorbance spectra for different concentrations of recycled water from Site 3.

A brief review of the literature has shown that the results obtained are consistent with those observed by other researchers (Weishaart et al, 2003; Broeke et al 2006; Pouet, et al 2007; Thomas et al, 2007). The UV spectra for water samples in the region of 254 nm tend to be featureless with absorptivity increasing with decreasing wavelengths as observed in Fig 1-3. Whilst the UV 254nm region can clearly be useful in the analysis of particular compounds/pollutants, it is generally agreed that nitrates and organic compounds (including benzenic surfactants used in detergents) expected in recycled water generate a much stronger signal at other wavelengths, notably in the region of 200-220 nm (as shown in Figure 1-3 above) (Thomas et al, 2007).

Whilst earlier cross connections research (O’Halloran et al, 2010) identified UV 254 nm as a promising indicator for detecting cross connections, this was based on results obtained using commercially available on-line UV-vis spectroscopy equipment (the S::CAN). Further investigation has shown the S::CAN uses a xenon flash lamp as the light source, a 256 pixel diode array detector and has a 100 mm path length hence

the ability to provide high sensitivity (Gruber et al, 2005). In addition to this the S::CAN uses complex algorithms and data obtained through PCA (principle component analysis) and PLS (partial least squares regression) from a large number of datasets containing UV-visible spectra and reference values (Broeke, 2006). The components used in instruments such as the S::CAN are expensive and high quality which is reflected in the price, which includes access to specialist staff to assist with analysis and interpretation of the collected data.

Whilst the project team have the capability to develop a UV 254 nm sensor that would have similar ability to the S::CAN for example, the cost and power requirements associated with this would make such a sensor prohibitive as an 'affordable in-home device'. As UV LED's become more expensive as the wavelength decreases, working in the range of 350-360 nm is significantly cheaper than working in the range of 250-260 nm which is in turn again cheaper than the 200-220 nm region where a sensor could readily detect differences as highlighted by Fig 1-3. Therefore the research focus has currently been on developing and refining a fluorescence sensor (355 nm) which meets the requirements of an affordable, stable and low power consumption device.

2.2 Fluorescence Spectroscopy

Fluorescence emission spectra matrices (also termed Excitation-Emission Matrices)¹ for recycled water samples were initially acquired at different excitation wavelengths in order determine the excitation and emission parameters for designing the in-line sensor. The fluorescence emission map for 100% recycled water obtained from Site 1 shown in Figure 4 indicates two distinct regions of fluorescence emission, as highlighted by the yellow circles. Three diagonal lines also appear in the figure, the first is simply the intensity of the excitation peak, whereas the second and third diagonal lines are the first and second order harmonics of the excitation signal.

¹ EEMs presented in the report were acquired after fluorometer lamps were warmed up for 1 h before beginning measurements. The data presented is in uncorrected raw format (arbitrary units). Appropriate data correction according to the methods of Murphy et al (Environ. Sci. Technol., 44 (2010), pp. 9405-9412) will be made and prior to the data being published in a journal article.

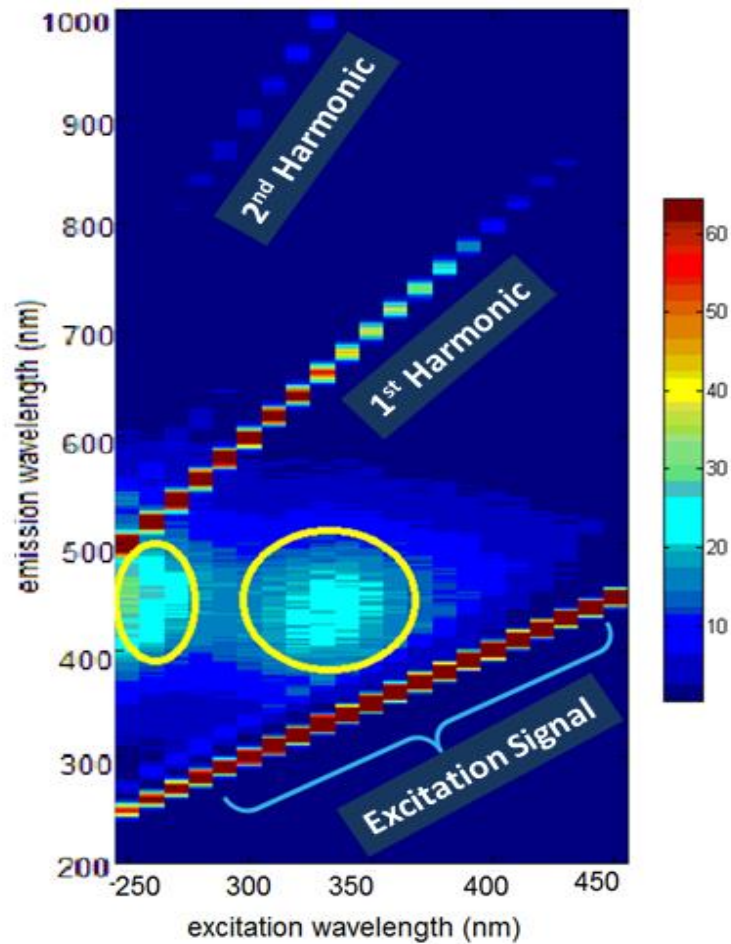
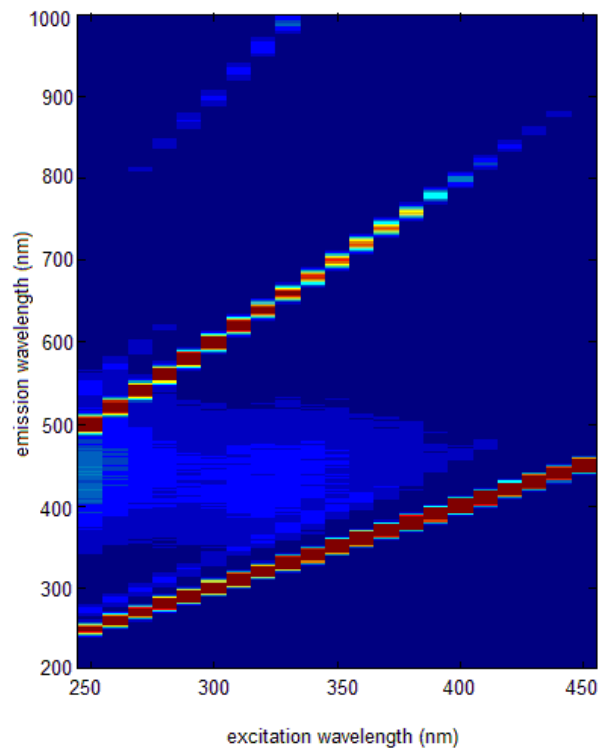
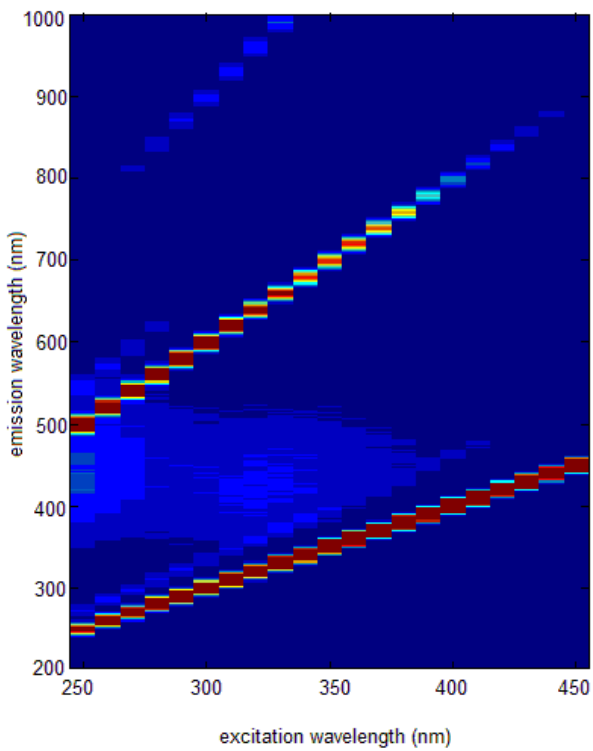
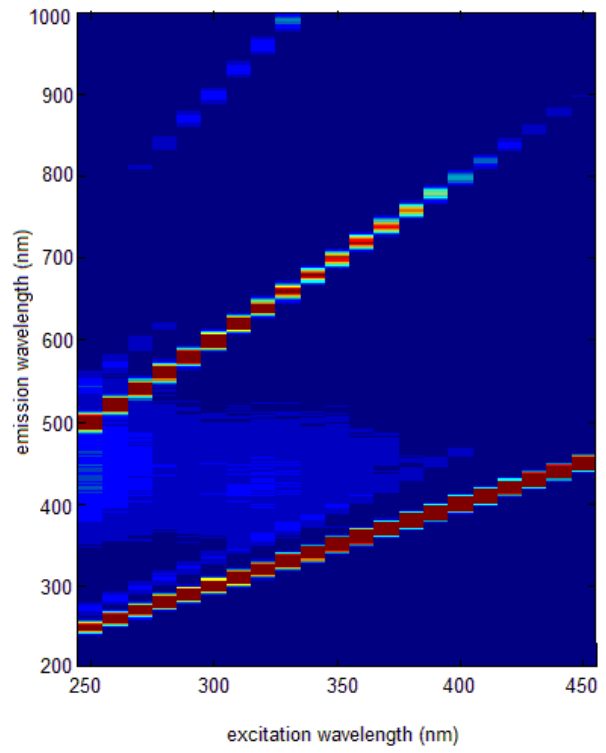
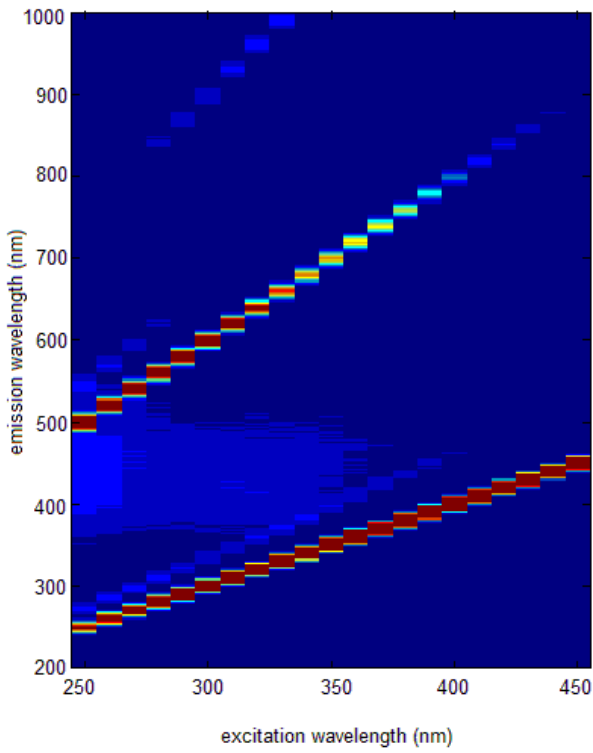


Figure 4: Fluorescence emission map for 100% recycled water obtained from Site 1. Emission spectra (horizontal axis) for different excitation wavelengths (vertical axis).

The first fluorescence excitation band is narrow and occurs from 250-270 nm, showing that by excitation at these wavelengths gives a strong fluorescence emission in the region from 400- 500 nm. When the excitation occurs from 270-300 nm the fluorescence emission is relatively weak, yet it substantially increases again when the excitation is between 310-370 nm. The consequence of this result is that an equally strong fluorescence emission may be obtained without having the need for an ultraviolet excitation source, and that significantly less expensive excitation sources (around 350 nm) can be employed.

Fluorescence emission maps for different concentrations of recycled water from Site 1 are seen in Figure 5, where it is evident that for each concentration, the two fluorescence emission regions are distinct. Clearly the fluorescence emission resulting from excitation in both regions (250-270 nm and 310-370 nm) becomes more pronounced with increasing recycled water concentration.



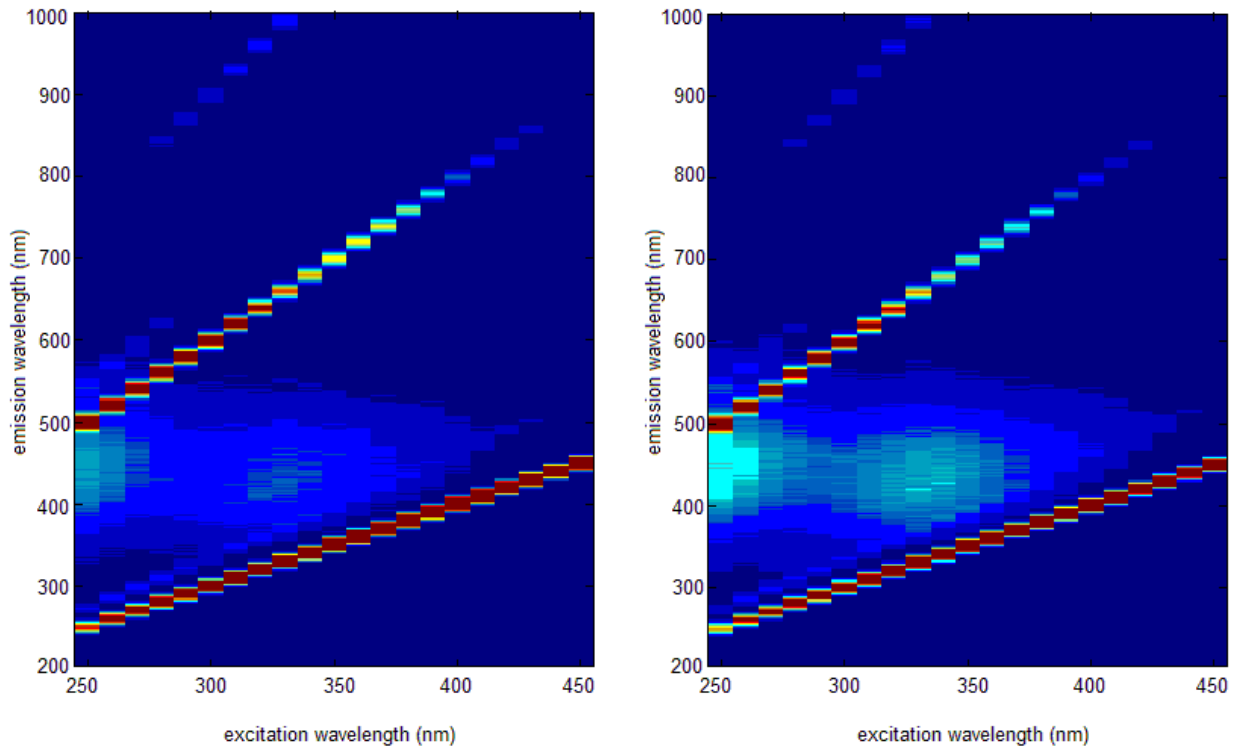


Figure 5: Fluorescence emission map for different concentrations of recycled water obtained from Site 1. (top left: potable, top right: 5%, middle left: 10%, middle right: 20%, bottom left; 50%, bottom right; 100%).

Figure 6-8 show the fluorescence emission of the recycled water samples from the different sites when excited with 355 nm wavelength light. For each sample, a linear relationship between the fluorescence emission intensity and recycled water concentration is observed.

The recycled water from Site 1 samples showed significantly lower fluorescence intensity and lower signal-to-noise ratio than those of either Site 2 or Site 3. For example, under the same experimental conditions, the fluorescence intensity at 450 nm for 10% recycled water contamination for Site 1 is around 6 arbitrary units at, whereas for sites 2 and 3 it is 10 and 23 respectively. For 100% recycled water contamination, the value for Site 1 is around 16 whereas for the other two sites it is 66 and 300, respectively.

The Site 1 samples are therefore likely to present the greatest challenge for detecting a 10% recycled water contamination, and consequently this sample set was targeted as the basis for designing and constructing our inline fluorescence sensor. Designing the system for this specification serves to make the inline sensor more robust in the field.

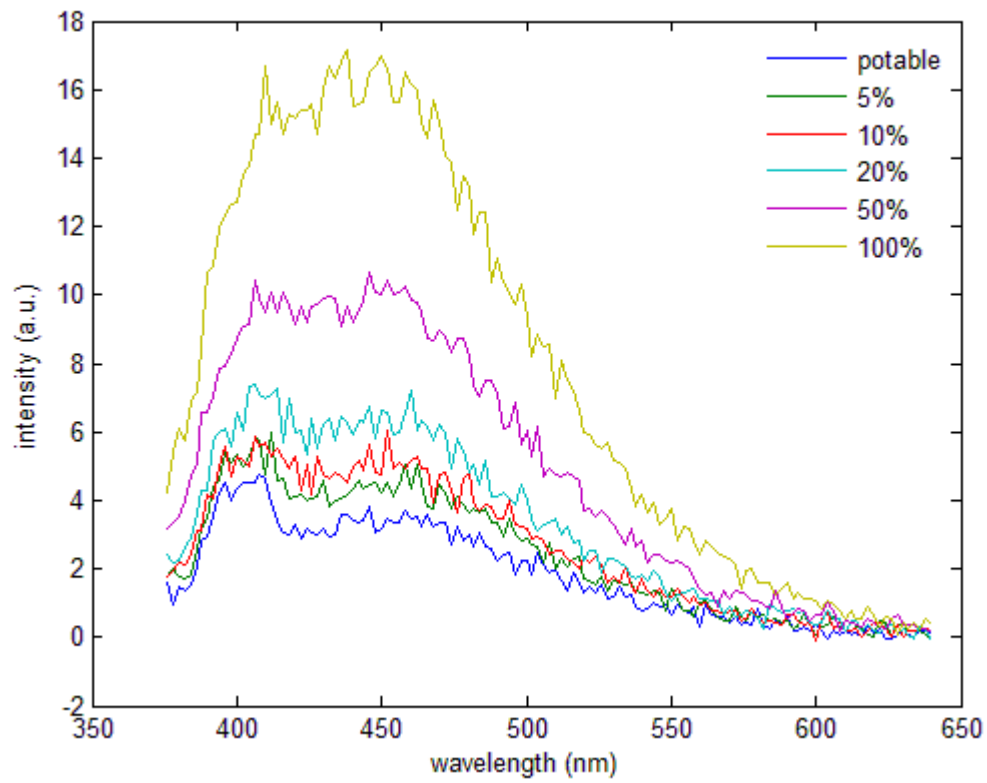


Figure 6: Fluorescence emission of different Site 1 recycled water concentrations at 355nm excitation wavelength

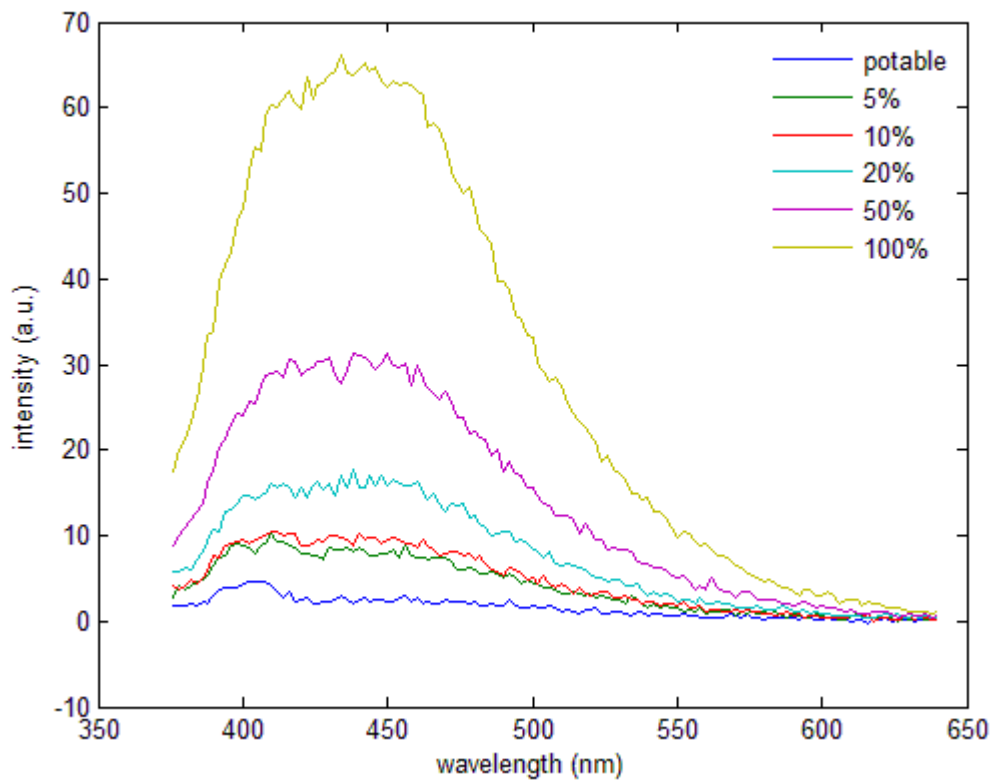


Figure 7: Fluorescence emission of different Site 2 recycled water concentrations at 355nm excitation wavelength

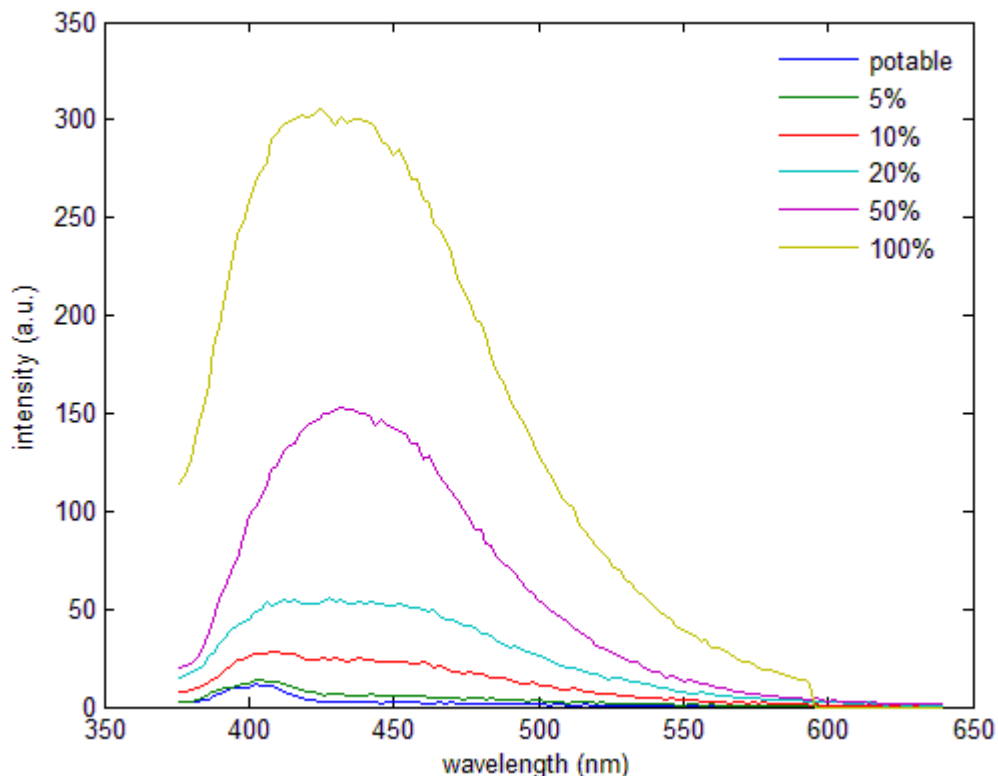


Figure 8: Fluorescence emission of different Site 3 recycled water concentrations at 355nm excitation wavelength

In addition to fluorescence detection, it was also shown that simultaneous observation of the scattering of the incident excitation source may provide additional detail regarding water characteristics. For example, when the excitation wavelength is 355nm, the intensity of the incident light changed noticeably for different concentrations of recycled water. Not just a result of more being of it being absorbed, but also a result of more light being scattered as a result of more contaminants in the samples.

Figure 9 shows the fluorescence emission of recycled water (between 380-600 nm) together with the excitation signal peak centred at 355 nm. Rayleigh scattering occurs from individual molecules as a result of changes in polarisability in a molecule that is scattering the light. Much like a turbidity meter measures scattering for micrometer size particles, scattering from nanoscale (or lower) sized molecules can result in an increase in photons being detected at 90° to the incident light. In this case, the intensity of UV excitation signal (the 355 nm peak) decreases when there concentration of recycled water increases. Moreover, a combined effect of scatter and absorption of the incident radiation is observed.

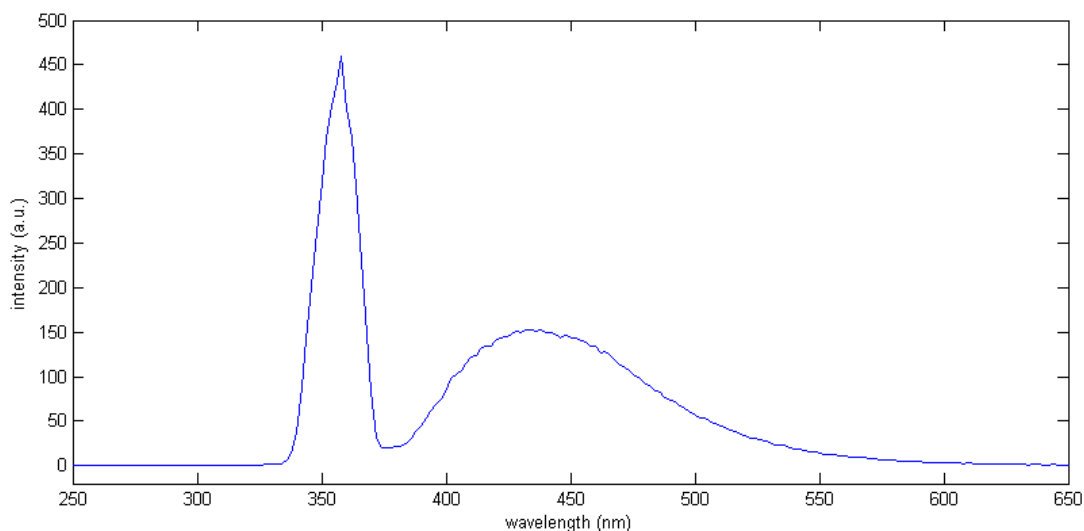


Figure 9: Fluorescence emission of recycled water (from 380-600nm) including the excitation signal peak centred at 355nm

This concept is illustrated in Figure 10 where for each of the sites a change in the intensity of the incident 355 nm excitation peak is observed when the recycled water concentration changes. Considering the data from Figure 10 and similar fluorescence maps (as in Figure 5), it may be possible that both fluorescence and scattering from an excitation at 310-370 nm may lead to a new synergistic method for distinguishing between recycled and potable water.

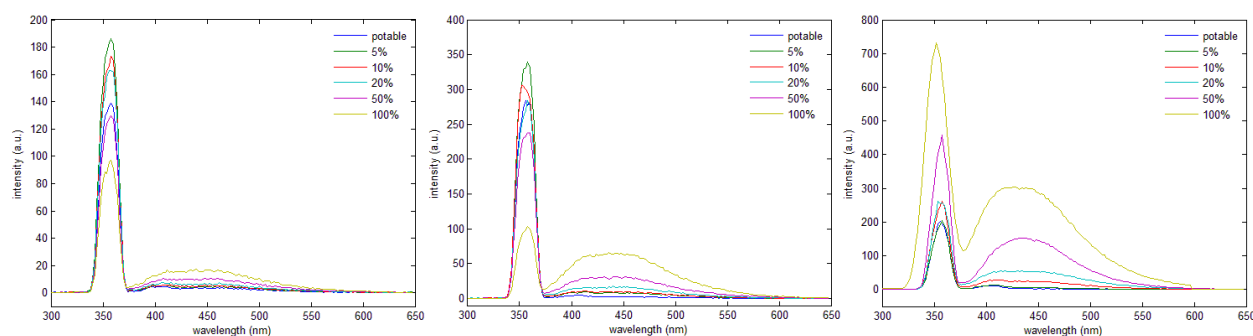


Figure 10: Fluorescence emission (from 380-600nm) of different recycled water concentrations at the different sites, including the excitation signal peak centred at 355nm. (left, Site 1, middle Site 2, right Site 3)

2.3 Discussion

From the UV-vis data across all samples and the discussion presented earlier, it is clear that directly measuring UV 254 will provide limited detail regarding the amount of recycled water contamination in the potable water. Although there were clear absorption bands at lower wavelengths, the development of absorption sensors for UV in the region of 200-300nm would involve costly light sources and detectors, making such a device less feasible economically.

Although the absorption was not capable of providing a clear indication of contamination at the higher end of the UV region, fluorescence on the other hand was capable of providing a clear distinction of recycled water from all three sites. Furthermore, the fluorescence results demonstrated that strong signals may be

obtained without having the need for a UVB (290-320 nm) or UVC (200-290 nm) excitation source, and that excitation around 350-360 nm (UVA) results in a clearly usable fluorescence signal.

Doing away with UVB and UVC sources and detectors and using 355 nm (UVA) excitation is a significant advance and enables the use of electronics and components which are less expensive than UVB or UVC for an inline sensor.

Owing to these fluorescence results, and the outcomes mentioned above, our focus in the development of the affordable inline sensor is now centred on monitoring fluorescence as a result of clearer distinction between contamination levels and stronger signal, and this has guided the development of the first prototype device.

3 Statistical analysis of lab Fluorescence measurements on recycled water from Site 1

Having established that the fluorescence approach was that which will form the basis of the sensing cross connections, statistical analyses were performed on the fluorescence data. Samples of potable water and recycled water were obtained from the Site 1 which represents the most challenging sample in which to obtain the fluorescence signal. These samples were retrieved directly from the recycled water treatment facility and thus are the same as those supplied to the distribution network. 10 samples of potable water and 10 samples of 10% recycled water/90% potable water mixtures (10% mix) were tested using a Cary Fluorescence Spectrophotometer. Samples were excited at wavelengths between 250 nm and 450 nm at 10 nm increments, fluorescence spectra were collected between 200 nm and 1000 nm.

To represent the current prototype sensor design the collected data was isolated to an equivalent excitation wavelength of 355 nm (taken as the mean of measurements obtained at 350 nm and 360 nm) and emission wavelength between 420 nm and 675 nm inclusive. The isolated spectra used for the statistical analysis is shown in Figure 11.

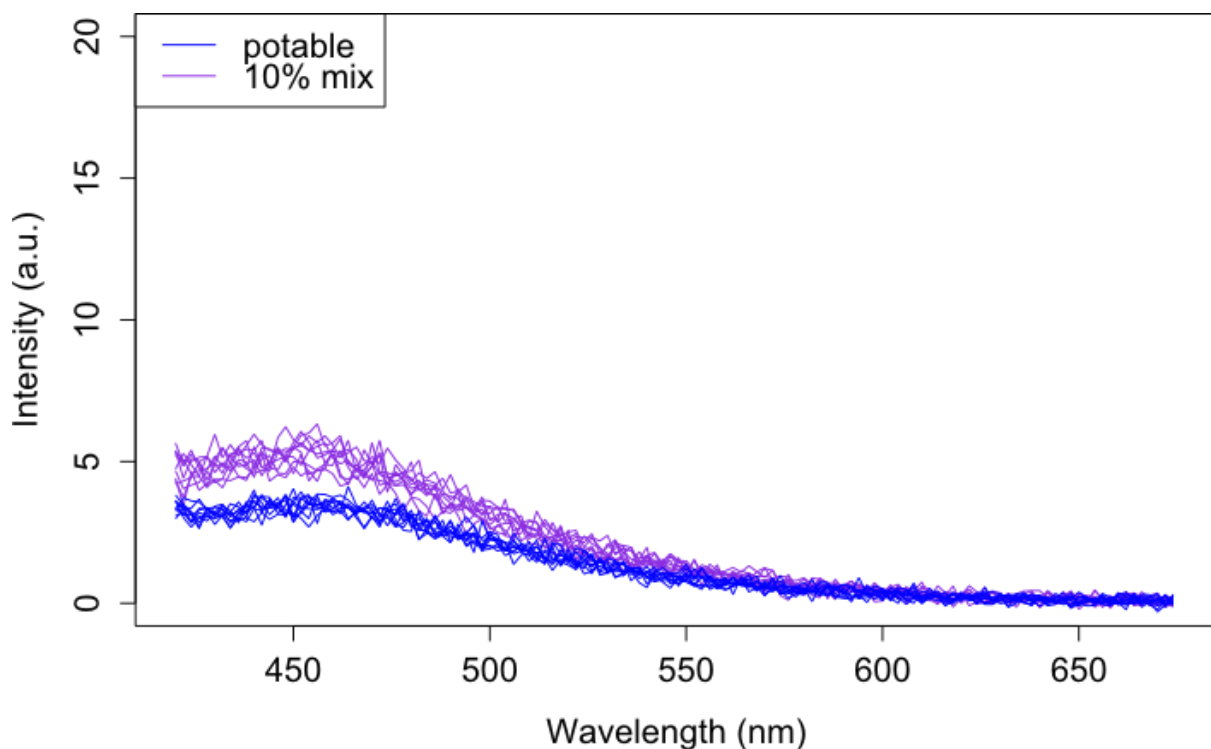


Figure 11: Example spectra used as basis for statistical analysis

The isolated data was then processed to produce a single value for each sample that is considered as representative of the signal collected by the current prototype sensor design. The processed values produced were the integrated summation of the fluorescence emission in the range from 420-675 nm (in keeping with the specifications of the developed prototype, discussed in the next section). These values were further treated to account for the varying transmissivity and sensitivity of components within the prototype. The adjustment reduces the strength of the signal across the 420 nm to 675 nm range. These values are shown in Table 1.

Table 1 Integrated fluorescence emission intensities of data treated to be representative of data collected by current prototype sensor design

Sample Number	Potable water	10% mix
1	97075.5	156608.4
2	97521.35	146734.6
3	98617.78	146993.6
4	97284.93	155770.8
5	100258.9	146102.8
6	100059.46	147119.1
7	102015.42	142591.3
8	103661.32	127172.6
9	98340.76	128523.9
10	100876.3	133487.5

Statistical difference testing was undertaken using the Welch t-test as detail previously in Milestone 2a report (O’Halloran and Gould, 2013). The combined data from all potable water sample was taken as representative of the potable water population. T-tests were then undertaken using varying number of replicate data sets of 10% mix samples; 10, 5 and 3. A confidence limit of 95% was used to identify a cross-connection. The results of each test are shown in Table 2. The 10% mix samples included in each test were selected randomly.

Table 2 Statistical difference (t-test) results

Test Number	Replicate of 10% mix samples	Results
1	10	Cross-connection detected with 95% confidence
2	5	Cross-connection detected with 95% confidence
3	5	Cross-connection detected with 95% confidence
4	5	Cross-connection detected with 95% confidence
5	3	Cross-connection detected with 95% confidence
6	3	Cross-connection detected with 95% confidence
7	3	Cross-connection detected with 95% confidence

4 In-line Sensor Development

The first prototype developed by the CSIRO cross connections team is shown in Figure 12. In its current configuration, the fluorescence signal is stimulated by a 355 nm UVA excitation source (LED – light emitting diode). The photodiode detector is located at right angles to the 355 nm excitation, and contains a filter layer over it, which blocks out light directly scattered from 355 nm source, ensuring that only fluorescent signals in the range from 420-675 nm are collected. The signal emanating from the detector represents the integrated summation of signals across the 420-675 nm wavelength range.

Accompanying the unit are the electronics, which include amplifiers, analog to digital converter and control stages (shown in Figure 13 and Figure 15) as well as driver circuits which allow precise control over the mode of operation, such as operation in continuous mode or in burst, whereby a signal may be collected at specified intervals. Such controls over the driving excitation source, photodiode detector and electronics and signal processing also provide a means of tuning the system towards different modes that can optimise power consumption levels within the unit.

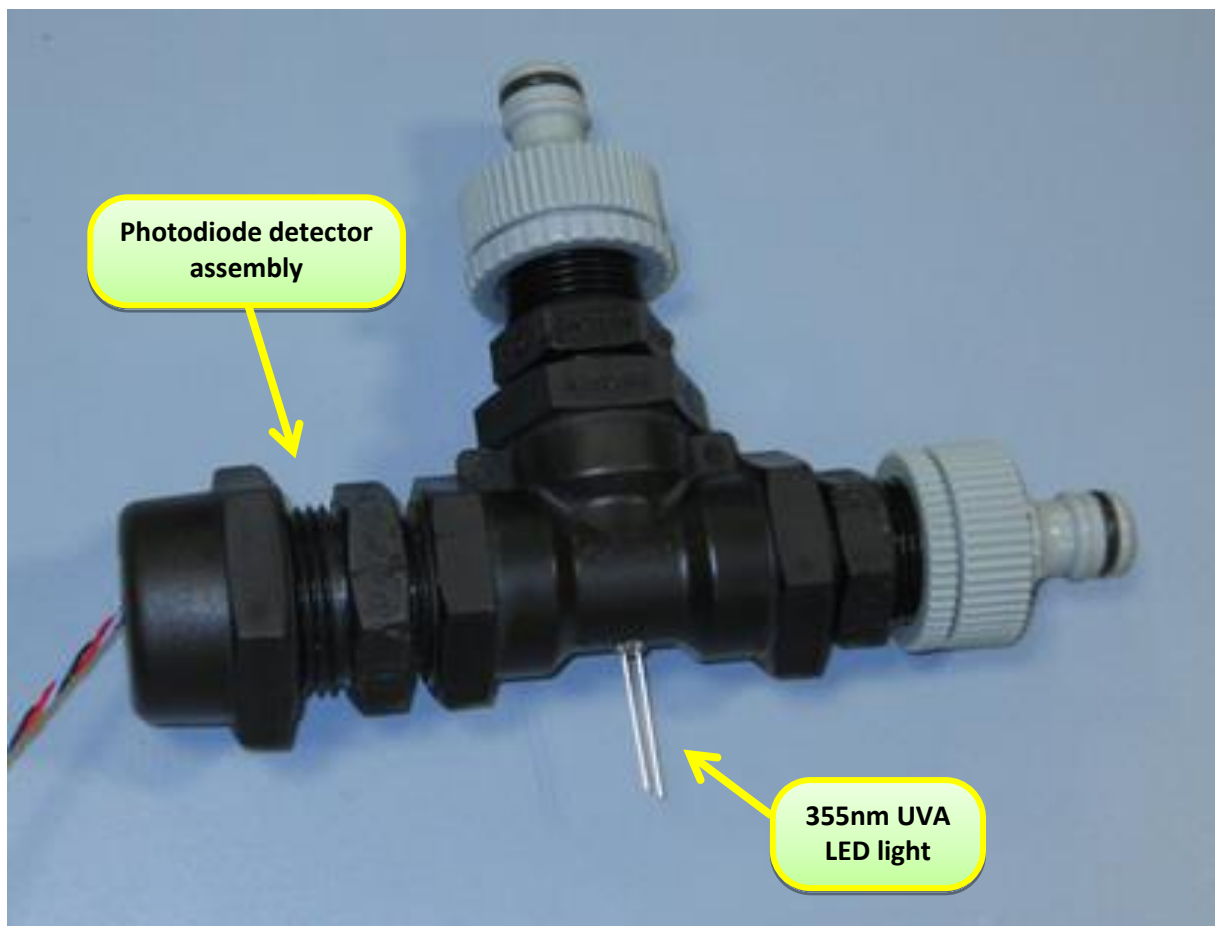


Figure 12: Photograph of first inline fluorescence sensor prototype.

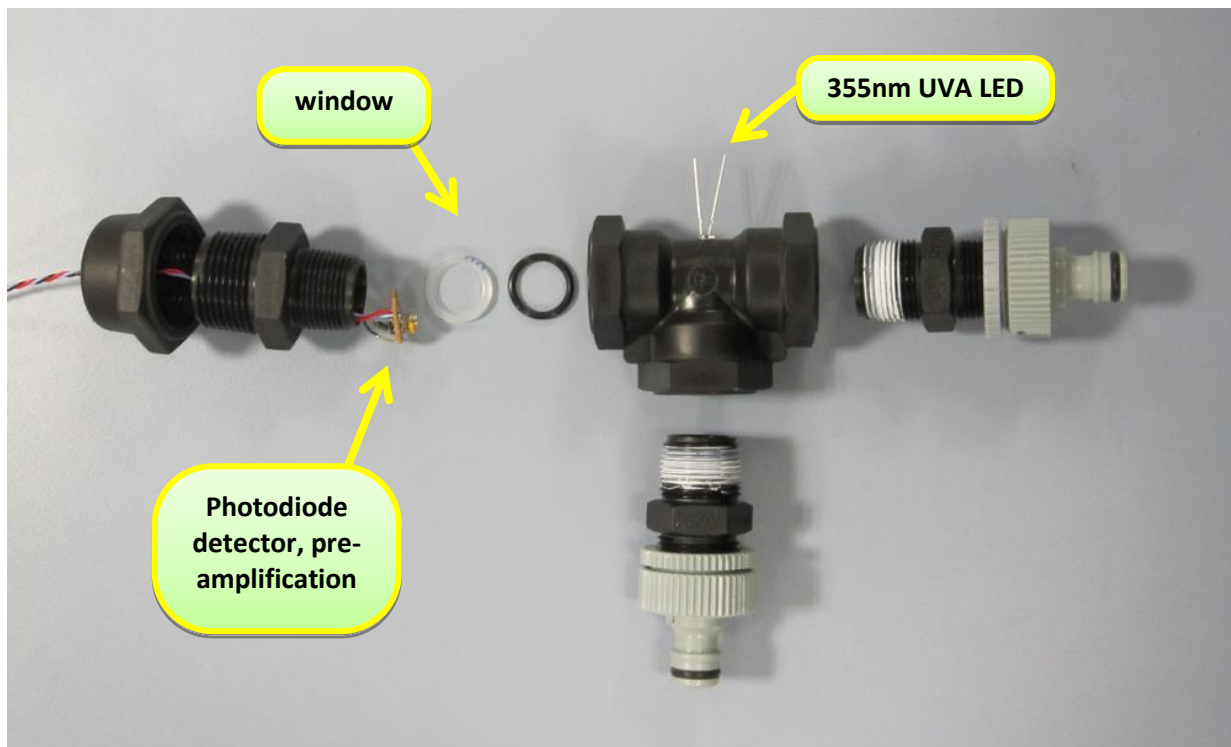


Figure 13: Inline fluorescence sensor prototype showing internal components

For initial testing and trials, appropriate amounts of tonic water were added to drinking water in order to simulate different fluorescence values. Tonic water was chosen as it contains quinine which provides a distinct fluorescence signal in the same region as that of the recycled water (Figure 14), and has previously been used as an internal standard. It was experimentally determined that the addition of 0.1% tonic water in potable water resulted in a fluorescence signal that was equivalent to 10% recycled water of the Site 1 sample set.

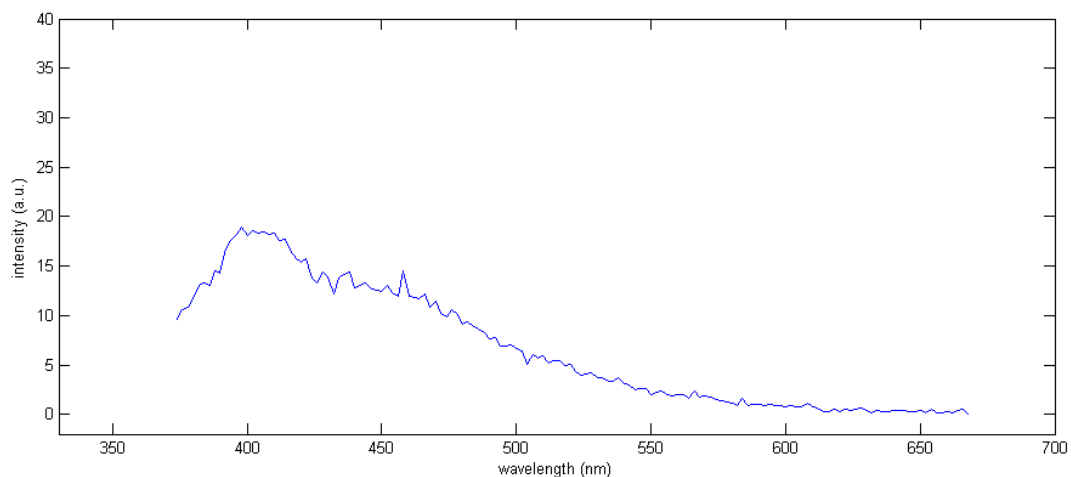


Figure 14: Fluorescence emission of a dilute tonic water sample

Throughout the prototype testing, appropriate amounts of quinine were added to drinking water in order to give a fluorescence signal that was representative of 10% recycled water contamination in the samples from the various sites. An example of the laboratory sensing setup for testing the prototype is shown in Figure 15.

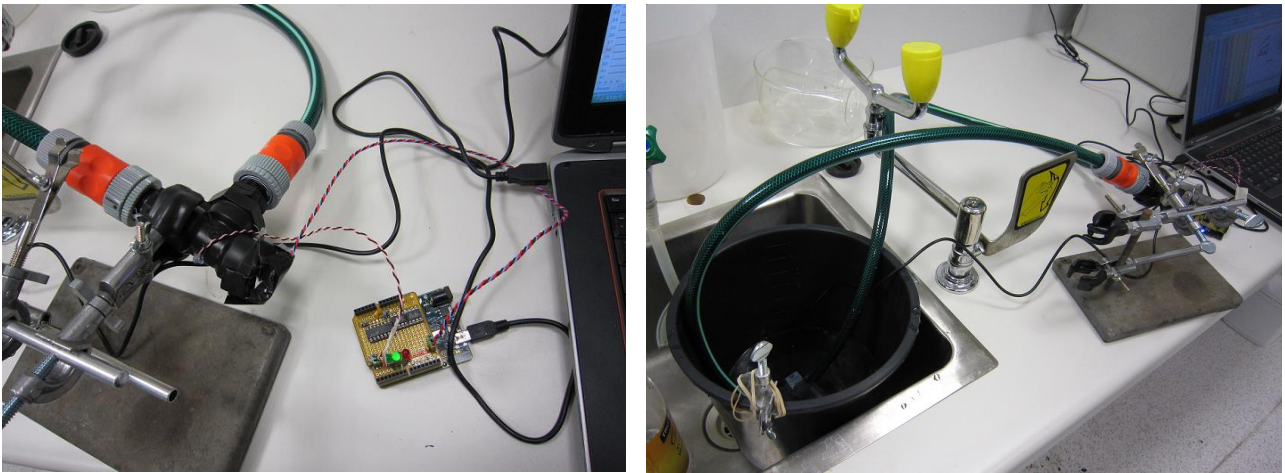


Figure 15: Experimental setup of inline fluorescence sensor prototype. Internal components

The output of the first developed prototype is shown in Figure 16, in which the sensor readings for different concentrations of tonic water are seen. Numerous replicates of the test were performed and there was a near-linear relationship between the sensor output and the concentration of added tonic water. For concentrations around and below 1% the sensor signal become noisy, which suggests the detection limit is around 1% tonic water, which equates to about 7% recycled water from Site 3, 20% from Site 2 and 100% from Site 1. However, it should also be noted that for Site 1, the difference between 1% recycled water and 100% does not constitute a significant difference in sensor output.

Improved sensitivity of the device can be achieved through changing hardware and their assembly. The major advances are likely through amplifier choice, increasing the focus of the LED source, sensitivity of detector and design configuration. A sensible initial target for guiding development is thought to be to detect 10% of recycled water for Site 1.

In its current configuration, the first prototype has been assembled for approximately \$200 in parts, which consist of water fittings, detectors, LEDs, amplifiers, microprocessors and electronics. It should be noted that for the second prototype, in some cases, changing electronics components may not directly translate to increased cost of the device. Also the cost of the sensors will scale down as more are produced.

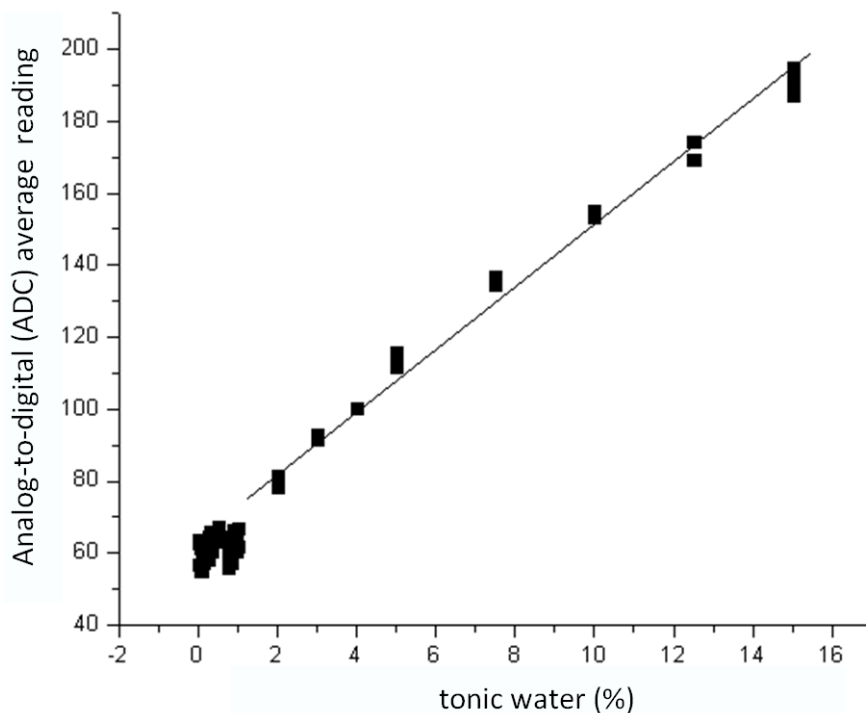


Figure 16: Inline fluorescence sensor prototype sensor readings for different concentrations of tonic water.

Issues of sensor stability, temperature compensation, calibration drift and fouling resistance will be addressed in greater detail once sensitivity requirements have been met.

5 Discussion and Future Direction

The work done to date has demonstrated that a combination of EC and fluorescence (355 nm excitation), and potentially scattering of the incident 355 nm excitation, is the most feasible means of detecting cross connections using a low cost inline sensor. In all cases, the samples were obtained directly from the recycled water treatment facilities and were representative of those in the distribution network.

EC carried out previously has shown that 10% recycled water detection can be achieved using our approach, even in scenarios where conductivities vary between (30 $\mu\text{S}/\text{cm}$ to $\sim 100 \mu\text{S}/\text{cm}$) for potable water and between (70 $\mu\text{S}/\text{cm}$ to $\sim 800 \mu\text{S}/\text{cm}$) for recycled water, at Site 1 which showed the greatest variability in data and thus presented itself as the most challenging sample set to analyse.

A first prototype for fluorescence has been built and constructed from off the shelf, low cost components, with the design driven by the experimental characterisation detailed herein. Our initial evaluation has shown that there is a need to increase the sensitivity and measures are currently in place to do so, which include altering the design and adjusting various system parameters such as amplifier gains, the LED source focus etc. It should also be noted that due to the 5 week delay in commencing the project, the prototype development is thus 5 weeks ahead of schedule.

Regarding the statistical analyses for the inline sensor, data acquired from the inline sensors during the field trials will be sent to a secure CSIRO data server and from there will be analysed regularly.

6 Conclusions

The results presented here demonstrated that the first prototype has the potential for being an affordable inline sensor for monitoring cross connections, which is in keeping with the aims of the project.

We have shown that monitoring the fluorescence signal is the best approach for doing so, and that the team is proceeding towards its goal of making the sensor affordable, with the current prototype costing approximately \$200 in parts. The first prototype fluorescence based inline sensor has been built and is based upon utilizing 355 nm excitation. This excitation can significantly reduce the cost of the device.

Ongoing work aims to produce a second prototype with sensitivity increased and lower detection limit, following which the device will be ready for deployment into an inline trial.

References

- A.C. Hambly, R.K. Henderson, M.V. Storey, A. Baker, R.M. Stuetz, S.J. Khan (2010). Fluorescence monitoring at a recycled water treatment plant and associated dual distribution systems - Implications for cross-connection detection. *Water Research* **44**, pp 5323-5333.
- J. van den Broeke, G. Langergraber and A. Weingartner (2006). On-line and in-situ UV/vis spectroscopy for multi-parameter measurements: a brief review. *Spectroscopyeurope.com* **18**(4).
- G. Gruber, J. Bertrand-Krajewski, J. De beneditis, M. Hochedlinger and W. Lettl (2005). Practical aspects, experiences and strategies by using UV/VIS sensors for long term sewer monitoring. *10th International Conference on Urban Drainage*, Copenhagen/Denmark, 21-26 August.
- R. O'Halloran, M. Toifl, R. Taylor and M. Winnel (2010). Detection of cross connection to potable water systems – Stage 2: Field trials of recommended detection parameters. *Water for a Healthy Country Flagship report*.
- R. O'Halloran, S. Gould (2013). An inline sensor to detect cross-connections between potable and recycled water systems in real-time. Milestone 2a: demonstration of lower detection limits. *Water for a Healthy Country Flagship*. July.
- M. Pouet, F. Theraulaz, V. Mesnage and O. Thomas (2007). *Natural Water*. In UV-visible Spectrophotometry of water and wastewater. Eds, O.Thomas and C. Burgess.
- O. Thomas, F. Teraulaz, S. Vaillant and M. Pouet (2007). *Urban wastewater*. In UV-visible Spectrophotometry of water and wastewater. Eds, O.Thomas and C. Burgess.
- J. Weishaar, G. Aiken, B. Bergamaschi, M. Fram, R. Fujii and K. Mopper (2003). Evaluation of specific ultraviolet absorbance as an indicator of the chemical composition and reactivity of dissolved organic carbon. *Environ. Sci. Technol.* **37**, pp 4702-4708

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