Heavy Metal Contamination of Residential Water in Yass, NSW

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The township of Yass, NSW has had historic issues with the supplied potable water from the Yass Water Treatment Plant (Yass WTP). Specific issues include hardness, turbidity and high total dissolved solids (TDS) content. No research had yet been conducted into the quality of water at the point of use for residents of the town. Water quality is tested at the point of release from the Yass WTP. This project aims to determine if there is heavy metal contamination of the supplied potable water in Yass, and the extent. Samples were taken from household taps and water tanks at the first flush and again after two minutes. Water infrastructure between the Yass WTP and residents has been anecdotally critiqued for its inadequacy and for issues related to ageing. Testing results indicate that there is no significant difference in water quality based on heavy metal contamination between rain harvested, tank stored water and town supplied water from the Yass WTP. The metals Cd, Se, Pb, Al and Ni were found in levels above the Australian Drinking Water Guideline (ADWG) recommended limits, inducing the requirement for further research.

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Final Project Report 2019, UNSW Canberra at ADFA
Nomenclature

ADWG = Australian Drinking Water Guidelines
ABS = Australian Bureau of Statistics
TDS = Total Dissolved Solids
RWH = Rainwater Harvesting
NHMRC = National Health and Medical Research Centre
HREC = Human Research Ethics Committee
FASS = Forensic and Analytical Science Service
US EPA = United States Environmental Protection Agency
TM = Two Minute Flow (Samples taken after two minutes of water flow)
FF = Samples taken at the first flush of taps being turned on.

Introduction

Australian cities and towns gain water for residential use from bore, rain harvesting or supplied potable sources originating from water catchments or reservoirs. The quality of these water supplies requires periodic testing to ensure that the water quality supplied to the user is of the standard outlined in the Australian Drinking Water Guideline (NHMRC, 2011). In the township of Yass in Regional NSW, residential drinking water is either rain harvested or supplied from the Yass Water Treatment Plant (Yass WTP) which draws water from the Yass Dam (Yass Valley Council, 2019). Yass experiences ongoing issues with water quality, specifically hardness, palatability and amount of total dissolved solids (TDS). Although these areas all currently conform to the ADWG acceptable levels, they are far from ideal and there have previously been occasions of widespread public dissatisfaction (O’Mallo, 2019. NHRMC, 2011). The Yass WTP puts out weekly and monthly reports regarding the quality, dissolved solids, suspended solids and pH of the water. This data set can act as an important frame of reference for further detailed analysis of the water quality at the user end of the water supply network. The aim of this study is to determine what heavy metals are present in the residential drinking water of Yass, compare the data obtained with that provided by the Yass Council, and compare the data from supplied potable water with the data from rain-harvested drinking water at the user end. This study will enable a more accurate representation of the water quality in Yass and make inferences about the quality of rain harvested water compared to supplied potable water.

A. Project Aims
The aim of this project is to test the quality of Yass’ water at the point of use for residents of the town. Metrics used to measure quality are the ADWG guideline values for dissolved elements and suspended elements. A comparison between the results obtained from the Yass WTP and the data obtained from sampling will be conducted to infer the quality of the water supply infrastructure between the WTP and the residences of Yass. Additionally, samples will be taken from rainwater tanks on the property (only residences with rainwater tanks will be chosen for the cohort of sampling locations) and tested in the same way as the supplied potable water. This will enable an assessment of the quality of the water from RWH systems currently in use by the residents of Yass. A comparison between rainwater tanks results and the results from the supplied water will be conducted to determine the relative value of utilizing RWH systems as a supplement to the supplied water based on heavy metal contamination.

B. Project Scope
This report is a part of a wider project scope supervised by A/Prof Robert Niven. The wider project ‘Heavy Metal Contamination of Residential Water in the ACT and Regional NSW’ investigates the water quality (in this sampling episode) in Yass, NSW and Belconnen, ACT. This project is bounded temporally, spatially and by contaminant type. The sampling plan is set out to test for a suite of metals that are both suspended and dissolved. The sampling locations are, for the purpose of statistical analysis, random. Letter drops were conducted in Yass intending to create project “sub-cohorts” that are linked by location, however as responses from residents have been essentially random, these sub-cohorts did not manifest. The data obtained from this project will not be analyzed temporally as only one set of samples will be taken from each location. From the results of this study, locations of interest may be identified for further ongoing investigation. Anecdotal notes from residents and news articles indicate that water quality (on the assessment basis of “drinkability”) fluctuates year-round. This will be qualitatively assessed with questionnaires during the sampling phase also.

Literature Review
A. Literature Review
Pollution of water by heavy metals poses serious health risks to humans and a serious ecological threat to the environment (Yang et al., 2019). The major descriptors of water quality in the context of treatment and usage are (micro)biological, chemical, physical and radiological (Smith, 1998). Heavy metals are one classification of contaminants in water and fit into the chemical and physical parameters of water, due to their nature of being either dissolved or suspended. This report will focus on the chemical (dissolved elements and pH) and physical (suspended elements) characteristics of water in the testing cohort. Heavy metals, by their nature, are not biodegradable and accrue in organisms over time (Xiao, 2017). Aquatic environments such as wetlands and including groundwater are the primary media through which heavy metals transport to organisms which appear in the human food chain (Wuana and Okieimen, 2017. Ahmad et al. 2011).

The treatment of water prior to distribution to the Australian public is standard practice in order to ensure that the concentration of contaminants is below the ADWG recommended levels. Interestingly, there is no legal requirement by water suppliers in Australia to adhere to the ADWG levels under federal policy. The guidelines “provide a basis for determining the quality of water to be supplied to consumers in all parts of Australia”, however state in the document that they are not mandatory. The ADWG outlines aesthetic and health-related guideline values for water. The aesthetic values are concerned with the “acceptability of water” to the user, and the health values are the concentrations at which “no significant risk is posed to the user over a lifetime of consumption” (NHMRC, 2018).

Management of Australia’s drinking water from a combined context of water supply and health authority was introduced in 1980 under the “Desirable Quality for Drinking Water in Australia” document approved by the Commonwealth (Australian Water Resources Council, 1980). Although the current ADWG levels are not legally enforceable, contracts that government agencies and councils have with water suppliers routinely list the ADWG levels in their contracts as readily agreeable targets of water supply quality. Currently, management of the water catchments surrounding Yass is multi-jurisdictional and is carried out under the “ACT and Region Catchment Management Coordination Group” which is authorized under the Water Resources Act 2007. The capstone document guiding the management of catchments is the “ACT and Region Catchment Strategy 2016-46” which outlines how the area should be governed to “produce a healthy, productive, resilient and livable catchment region” (ACT Government, 2016). In this report, the Yass Council identified that as the population of the ACT and region grows, water and wastewater treatment will continue to be a challenge, particularly for rural areas. Part of the strategy of the Yass Council to reduce the impact of a water crisis event is encouraging residents in urban areas to purchase rainwater tanks for potable use. Rainwater tanks in urban areas can also reduce the risk of flooding by minimizing the flow of water into stormwater systems (Al-Batsh, 2019). Residents that live in non-urban zones surrounding Yass are required as a part of development consent to have rainwater tanks for potable use and firefighting also (Yass Valley Council, 2004).

Management of the Yass Water Treatment Plant falls under the Yass Valley Council, who have been issued an Environment Protection License from the NSW Environmental Protection Authority (NSW EPA, 2002). The responsibilities of the license include monitoring of the pollutants that are discharged and monitoring of the level of contaminants in the water supplied to the user, amongst others.

The Yass Valley has two primary issues regarding its water: Supply and quality. Supplying the valley was addressed in 2013 when the Yass Dam wall was raised, and in 2015 when funding was awarded to supply the nearby town of Murrumbateman with a water pipeline. The second issue is the palatability of Yass’ water, 15% of people surveyed in the ACT and region in 2015 stated that poor water quality in residences was at least a moderate issue (ACT Government, 2016). The Yass WTP conducts weekly and monthly testing for a range of health and aesthetic metrics as prescribed by their EPA license and the ADWG (Yass Valley Council, 2019). An example from April 2019 of the testing reports can be seen at Table 2. The monthly chemical analysis outlines a detailed schedule of chemicals that exist as dissolved and non-dissolved particles in the tested water. These reports provide accurate information about the water leaving the water treatment plant, however accurate data does not exist for the water quality at the

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Guideline Value</th>
<th>Units</th>
<th>Tested Value</th>
<th>Meeting guideline values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free Chlorine</td>
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<td>mg/L</td>
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<td>Yes</td>
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<tr>
<td>Total Chlorine</td>
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<td>mg/L</td>
<td>0.84</td>
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<tr>
<td>E. coli</td>
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<td>CFU/100mL</td>
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<td>Yes</td>
</tr>
<tr>
<td>Manganese (total)</td>
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<td>mg/L</td>
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</tr>
<tr>
<td>Aesthetic related test results</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alumimum, soluble</td>
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<td>mg/L</td>
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<tr>
<td>Iron (total)</td>
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<tr>
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<td>Yes</td>
</tr>
<tr>
<td>Colour</td>
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<td>Hazen Units</td>
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</tr>
<tr>
<td>Turbidity</td>
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<td>NTU</td>
<td>0.19</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 1. NSW FASS Laboratory results of Yass WTP supplied water.
user end. The Yass WTP does not conduct “user end” testing as some other water treatment facilities (e.g. the Mt. Stromlo Water treatment facility operated by Icon Water). This project aims to fill this data gap.

**Methods**

**A. Human Research Ethics Committee Approval**
The project team was advised by the New South Wales Human Research Ethics Committee (HREC) that an ethics approval process was required to be undertaken. This was required as the research team had to enter residents’ houses and interact with the residents. Additionally, both personal information and location-specific data was required to be collected as a part of the analysis on the sample results. The results of the study may produce information that can be viewed as distressing to participants as toxic metals are being tested for. Ethics approval was sought at the “More Than Low Risk” level due to this fact. The HREC review board approved this project, titled “Heavy Metal Contamination of Residential Water in the ACT and Regional NSW” under reference code HC190211. The approved supporting documentation for this study is attached at Annex A1-A8.

**B. Project Participant Recruitment**
In accordance with the ethical framework, participants were recruited into this study via a letter drop conducted in Yass. Annex A4 was supplied to the resident with a reply-paid service for an optional response. Facebook posts in two community group pages were also made with the script approved (listed in Annex A7).

**C. Sampling, sample preparation and storage**
Samples were taken from participants house supplied mains taps and rain tank taps (if rain tanks were installed). The taps connected to the supplied town mains were only sampled if they had not been used in the last 18 hours. This was achieved by sampling (usually) a spare bathroom or laundry tap. The supplied town water taps were sampled at first flush, then let run for two minutes in accordance with AS/NZS 5667.5-1998 (2016) prior to a second sample being taken. The samples were taken straight into glass beakers that were acid washed between use. The water taken was syringed at the time of sampling through .45-micron filters into 200ml storage bottles prepared with a single drop of 67% ICP grade HNO₃ to prevent any contaminants leaching into the storage container. The filters were kept in petri dishes for re-dissolution at a later stage. Samples were stored at ambient temperature for transport to the UNSW Canberra laboratory, where they were then kept in a temperature-controlled environment at 25 degrees Celsius. These filtered samples were then analyzed through the ICP-OES for the target contaminants not more than 28 Days from the date of collection. A full method, sampling procedure and quality assurance/control outline can be found at Annex B and C.

**D. Quality Assurance and Control**
During Sampling, residents’ houses were given unique identifying codes which could be related to the samples taken from that location. Samples were code-identified in order to anonymize the residents’ personal information from the study in adherence with the NSW HREC requirements.

**E. Equipment Preparation and Method**
The samples were tested with a Perkin Elmer Inductively Coupled Plasma Optical Emission Spectrometer. (ICP-OES). The ICP was calibrated with a set of standards prepared by the research team. Single and Multi-element standards were prepared at 0.1, 1 and 5 PPM by volume using a volumetric flask. A confirmation of the accuracy of the flask was done using scales accurate to 1/1000° of a gram. The full method of the standard mixtures’ preparation is attached at Annex D.

**F. Testing Method**
The testing method involved using an ICP-OES for atomic spectroscopy analysis of the samples. This method was chosen as it is the most accurate form of analysis available to the research team for this project. Additionally, Confirmation of results are intended to take place with an external laboratory for any results that returned a measurement value above the ADWG health limits. The most appropriate form of analysis suggested by four different labs contacted is the ICP-OES Method.
Results

A. Participant Response, Questionnaire Results and Anecdotal Data

During the letter dropping episode, n = 100 invitations were dropped with n = 15 residents responding to take part in the study from this means. From social Media Advertising (Posts on Yass Valley community Facebook group pages), six respondents were gained. Out of the total 21 respondents, eleven residences were sampled during the sampling phase with a total of 34 samples being taken.

In discussion with Yass residents and from questionnaires, many anecdotal notes were gained. A common theme amongst seven out of eleven residences sampled was the residents’ statement that the supplied town water was much “worse” (quantified by odor and color in all cases) in the summer months. Additionally, all residents in the sample group had used store bought water at some point in the last year to use in place of the “undrinkable” supplied water. Only two out of the eleven residents stated that they drank the supplied town water, and only after it was filtered by a filter on their property. Nine out of ten residents had rain-tanks installed and stated that their day to day use of their rain-tank water was for their garden, laundry use and toilets.

The house identification measures followed during this project are in accordance with the HREC approval. Each house was given a code identifier and all samples were linked to that code in order to protect the privacy of the residents. The returned Expression of Interest forms, House Identification Record, completed questionnaires and Consent forms will not be attached to any electronic copies of this report. They will be filed as a confidential annex to this report and kept secure in the School of Engineering and Information Technology Canberra Campus.

B. Initial Testing Results

ICP-OES Results returned from the initial batch of testing indicated that the deionized water source used for the preparation of the standard solutions of elements was contaminated. The contaminant elements were Na, Ca, K and Mg. The results returned by the ICP-OES analysis also indicated that two of the five solution sets returned values that were not congruent with the expected (labelled) concentration levels. Due to the combination of these factors and the way the ICP-OES is calibrated, the dataset produced was not useable for the analysis required for this project and is excluded from this report.

C. Results

The second set of standard solutions made with a different deionized water source (gained from a returned sample results that are summarized below. A full table of raw data is available at Annex F.

General Trends

![Figure 1. Median Measured Value of Elements Tested.](image-url)
Figure 2. Yass WTP September Published Values and Median of Measured Values.

Figure 3. Sample and Duplicate Consistency from House Y2.

Elements Exceeding the ADWG Recommended Values

(a) Nickel

(b) Selenium
Discussion

A. Initial Standard Solution Contamination

The initial results gained from the first set of standard solutions were found to contain contaminant elements in the deionized water source used for their preparation. The elements Na, Mg, K and Ca were found in up to 10 ppm in the water source. The deionizing machine used in the School of Engineering and Information Technology; Canberra Campus is used primarily for determining element concentrations in the 100-10 000 ppm range. The system used to deionize the water is enough to remove contaminants to the required standard for Civil Engineering-based research. Due to this range, previous experiments had not discovered that the water was contaminated with the above elements. This project is working on the 0.001 – 100 ppm range and the deionizing system did not deionize the water to the standard required.

The initial standard solutions returned results that had concentrations not congruent with the expected concentration. The initial solutions created were made over six weeks prior to the testing date as testing was pushed later than expected due to personnel availability. The solutions containing Na were observed to grow algae inside them and were re-made two days before the testing date. The contamination of the deionized water negatively affected the resulting data due to the nature of how the ICP-OES conducts its calibration method. Contaminant elements skew the calibration curve and make the data returned from the analysis of unknown concentrations of elements in field samples unusable.

Once the contamination of the deionized water source was identified, the standard solutions were re-made with water sourced from a Merk Milli-Q water purification system and the standard preparation and acid washing method detailed in Annex D. These new standard solutions returned data that was able to be used for analysis.
B. Data Accuracy and Uncertainty, Quality Assurance and Control

Due to the sample size of this project (eleven houses sampled, 34 samples taken), the data gained from this project must be treated separately depending on the analysis to be conducted. For trend analysis across all sampling locations (houses), the sample size is appropriate for qualitative analysis and conclusions only. Attempting to make quantitative conclusions about trends across houses does not meet the NEPM recommendations for sample size. For analysis on individual houses regarding the difference between FF and TM measurements and for indicating whether the various metal concentrations meet the ADWG guidelines, quantitative analysis is appropriate as the accuracy of measurement methods (outlined below) fall within the advised boundaries for detection limit and testing procedure.

The methods used for sampling and testing are congruent with the requirements laid out in the 2013 NEPM, the ADWG and the “Guidance on Sampling Water used for Drinking” (AS/NZS 5667.5-1998 (2016)). Uncertainty introduced from laboratory procedures was calculated to be +/- 1% considering the accuracy of auto-pipettes used for making the standard solutions and filling the volumetric flasks.

Duplicate samples were taken during the sampling program to validate the accuracy of the sampling procedure. The uncertainty introduced in the field sampling is calculated to be 5.3%. This was done by comparing the duplicate samples and finding the difference between them to calculate relative error. As can be seen from Figure 3 and the data attached in Annex F, the largest difference in measured value was from the TM measurement of Na (4.6 ppm difference, equating to 5.3% uncertainty). The combination of these two avenues of uncertainty (6.3%) will be taken as the relative uncertainty for all data.

The ICP-OES Detection limits for dissolved elements is attached at Annex G. As the data obtained sits well above the detection limits of the machine, measurement precision has been considered as being at the necessary standard for the concentration range obtained from the data. The detection limit of the ICP-OES changes for each element and at maximum, the detection limits sit two orders of magnitude below the health and aesthetic limits outlined in the ADWG.

A blank sample (only deionized water and one drop of 67% HNO₃) was used as a part of the calibration of the ICP-OES as a control sample free of contamination. This allowed the contaminated samples to be measured against a null case and differences quantified in ppm. This part of the testing methodology could have been improved by putting in other blanks within the sample batch to confirm the accuracy of the ICP-OES and to deliver a higher level of confirmed quality control in laboratory methods.

The QA/QC measures taken are outlined in the SAQP attached at Annex C. A chain of custody for was filled out for each sample and is attached at Annex H.

C. Trend Analysis

Figure 1 outlines the mean values of all elements tested across the sample cohort of houses. The graph clearly indicates the differences in First Flush (FF), Two Minute Flow (TM) and Tank (TANK) water sample averages. From this, it is seen that the notable differences are the lowered levels of Mn, B, Ni, Zn and Cu in the TM samples compared to FF. Additionally, the heightened levels of Co, Fe and Al in the TM compared to the FF. These results indicate that the elements that have a higher concentration in the FF samples may arise from localized sorption of metal particles into the water from the immediate water pipework within the house. This is expected of (particularly) Cu as many houses tested are of the age when copper piping was common for plumbing use. The significant downward spike in Zn may be due to the commonality of galvanized steel for use in plumbing, fittings and taps. Similarly, the spike in Ni may be due to the use of modern stainless steel in tap finishing’s. Elements that raise in concentration from FF to TM sample sets would suggest that those elements are being introduced from factors outside of the immediate piping structure. As only cold water was sampled, hot water systems that operate from a constant-temperature storage tank (common to Australian households) would not have affected the samples. The raising of Co, Fe and Al in the TM flow compared to the FF flow, indicates that these elements may be originating “upstream”.

Tank water shows much higher Zn, V and Mn concentrations compared to the TM flow. The Mn concentration may be due to rainwater containing Mn naturally (Deutch et. Al., 1997). When compared with the Yass Valley Council published results in Figure 2, it shows that the YVC measured higher Mn levels that the TM flow samples. Zn levels in the Tank samples may be due to detention time of water in galvanized steel tanks for long periods (months) of time.
The results published by the Yass Valley Council from samples taken on September 3, 2019 are displayed against the TM flow results (sampled between 15-22 September 2019) in Figure 2. These results from the YVC are the closest (in terms of time) that could be gained. The graph may be interpreted to show general trends regarding the effect of the piping infrastructure on the water going from the water plant to resident houses. The graph shows high similarity between the elements Mo, Fe, Ba, Ni, Al, Mg, Ca and Na. This trend indicates that these dissolved metals may be present in the town water due to factors upstream of the water treatment plant, or that the water treatment plant processes may have these metals as byproducts. It also reinforces the legitimacy (quality assurance) of the testing methods for these elements as the probability of these elements appearing at such similar concentrations in the test water Differences in some metal concentrations such as Cr, Mn, B, As, Se, Zn, Cd and Cu may infer that these metals may be being introduced to the water via the water piping infrastructure between the water treatment plant and the residences. 

Figure 4a shows that two of the houses sampled returned Ni concentrations above the ADWG limits. Figure 4b shows that 11 of 34 samples contained Se to a higher concentration than the ADWG limit. Of the eight contaminated residences, seven showed high Se levels in the supplied town water only, without high Se levels in the tank water samples. In the same seven residences, Se was always of a higher concentration in the TM sample than the FF sample. This could indicate that dissolved Se may speciate with the contaminants present in the residence water infrastructure over an extended detention time (More than 18 hours), moving to a suspended form rather than dissolved.

In every sample taken, Cd concentration was higher than the ADWG value of 0.002 ppm. The published result from the YVC indicates that cadmium is almost non present in the water at the WTP location, indicating a strong likelihood that Cd is being introduced to the water via infrastructure materials common across both town water piping and rainwater tank materials. There is some evidence that Cd may be introduced via stainless and galvanized steel (Tjandraatmadja and Diaper, 2006).

Pb and Al are shown in Figure 4d and 4e. The three houses shown containing these contaminants display the concentrations in the same order of magnitude as the ADWG limits. In both cases for Pb, the measurements exceeding the limit are the FF measurements, indicating that the house piping may be leaching Pb into the water with an extended detention time.

This project was limited to the analysis of the dissolved metals (those passing through a 0.45-micron filter) in sampled water. Further analysis could be done on the total metal content of water using the material caught on the filter papers used during sampling. This was not done due to time constraints however may provide further insight into differences between FF and TM measurements. Additionally, this project was limited to the measuring of heavy metals only. From the anecdotal data from residents, further investigation could be initiated on the biological contaminants in the supplied town water. Comments made about the drinkability of the town water may stem from biological contaminants as the difference in metal contamination between tank and town water was comparatively small, and residents did not comment that their tank water had drinkability issues.

Conclusion and Recommendations

This project involved the recruitment of a sampling cohort, sampling, testing of samples and analysis of raw data and trend patterns to investigate user-end heavy metal contamination of drinking water in Yass, NSW. It aimed to assess the usage of RWH systems compared to supplied town water and to test the quality of supplied town water based on metal contamination. The key findings and recommendations of this research are:

- Concentrations of contaminant metals in rainwater tanks did not differ significantly from the supplied town water.
- Concentration of Cd was higher than the ADWG limit in all samples taken. This source of contamination should be investigated further.
- Further investigation should be completed on the biological contaminants of Yass water.
- Yass water infrastructure may be causing contamination of As, Se, Zn, Cu and Cd and should be investigated further.

Acknowledgements

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References


-alt water


