WHAT LEVEL OF DISINFECTION DO WE NEED FOR STORMWATER REUSE AND WHY?

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ABSTRACT

Risk management is a vital part of any project, and stormwater reuse projects are no exception. For stormwater harvesting, risks are largely unknown and vary depending on the catchment, inter-rain periods, rainfall intensity, storm duration and intended reuse to name a few factors. When the intended reuse is irrigation a common approach in urban environments is to pre-treat water using a Gross Pollutant Trap (GPT) before storage and disinfect the water using Ultra Violet (UV) light prior to reuse. Current guidelines provide advice on the expected or desired level of reduction of indicator organisms (commonly E. coli.) prior to reuse, as well as maximum turbidity levels (NTU), which has commonly been used as an indicator of the expected performance of the UV disinfection.

Ku-ring-gai Council has adopted stormwater harvesting as a way of improving the quality of sports fields to accommodate increasing demands. There are six fully operational systems with a further two under construction and only one is equipped with UV disinfection.

This paper presents the results of water quality sampling undertaken by Council as part of a risk management review. The data from this study suggests that with appropriate design and management regimes, stormwater reuse schemes are likely to comply with the intent of current NSW and National guidelines without necessitating disinfection to address health risks associated with the presence of pathogens. However these conclusions are based on a limited data set and are only valid for the systems assessed as part of this study. These results may not necessarily be directly transferable to other systems.

1 INTRODUCTION

Urban stormwater pollution is a well known and understood problem. Since the 1990s Australian government agencies have been promoting the need to decrease pollutants such as sediments, rubbish, nutrients, pesticides, detergents, hydrocarbons and other chemicals. Slogans such as *"the drain is just for rain"* were used to encourage the community to be mindful of what they wash down the stormwater system (DEC 2004). In NSW this and similar campaigns arose from the concern associated with the impact of urban stormwater on the natural environment and areas used for recreation. Even though the impacts on human health from stormwater have been a concern for many years, practitioners have been encouraged towards reuse and recycling schemes as part of a move to integrated urban water management.

In 2004 Ku-ring-gai Council introduced a seven year environmental levy. One of the major funding areas was the implementation of stormwater harvesting systems to provide irrigation for playing fields. These schemes were to provide fit for purpose water from a sustainable source with the outcome of improving the quality of sports fields. Environmentally, the project sought to provide benefit to the local waterways and lessen the demand on potable supply. The genesis of this program also stemmed from the drought affecting Sydney and subsequent water restrictions limiting the use of potable water for irrigating open space areas.

The development and delivery of this program has been cognisant of the many risks associated with stormwater reuse. Institutionally these ranged from the acceptance and subsequent maintenance of the systems. Environmentally, risks include whether the designed water quality treatment systems would perform to their expected standard. Social risks include whether the provision of non-potable standard of water would cause unnecessary risks to public health. It is the latter factor that is of interest to this paper.

In New South Wales (NSW) risk management procedures are outlined by both the State Government (DEC 2006) and Australian national guidelines for stormwater harvesting and reuse (NHMRC 2009). These outline the large array of risks and associated factors that need to be considered when planning, designing, constructing and operating stormwater harvesting systems. When the intended reuse is irrigation, a common approach in the urban environment has been to pre-treat water using a Gross Pollutant Trap (GPT) before storage, followed by disinfection of the water using Ultra Violet (UV) light prior to reuse. Current guidelines provide advice on the expected or desired level of reduction of indicator organisms (commonly *E. coli*.) prior to reuse as well as maximum turbidity levels, as NTU (NTU - nephelometric turbidity units), commonly used to provide an indication for the expected UV disinfection efficiency.

This investigation has been undertaken in recognition that the recommended indicator organisms, Faecal coliforms, *E-coli* and enterococci, are not necessarily indicative of other pathogens that may be present (ANZECC 2000). Currently, *E-coli* is regarded as a preferred indicator when testing fresh waters for recreation (ANZECC 2000) and for harvesting systems (DEC 2006). However, only a small number of *E-coli* species are pathogenic to humans and these usually occur in very low numbers (NHRMC 2009).

In 2010 Ku-ring-gai Council had six fully operational stormwater harvesting systems with a further two under construction. Of these eight systems, one is equipped with UV disinfection, while the others rely on access control as a means to manage risk to public health. Access controls include closed storage, signage, sub-surface irrigation (Lindfield Soldiers Memorial) and irrigation at night for overhead sprinkler systems.

This paper focuses on analysing the potential risks to human health as a result of exposure to micro-organisms that arise from using stormwater for irrigation of urban sports fields. These risks have been evaluated to guide the future management of these and future facilities.

2 BACKGROUND

2.1 Overview of the Guidelines

National and State guidelines currently provide a variety of approaches and protection levels that can be implemented in order to mitigate risks depending on the intended use of harvested stormwater (NHMRC 2009, DEC 2006). The guidelines include a variety of actions such as coarse treatment (litter screening); biofiltration; wetland treatment; chemical treatment; cartridge/disc filtration; and treatment with ultraviolet (UV) light. The guidelines do not specify the use of particular treatment techniques; rather they offer background information on relevant scientific research. They indicate the most appropriate method and level of treatment will depend on the intended end-use of the water. Both guidelines have been produced to encourage the use of recycled water, which is generally viewed as an underused resource (NHMRC 2009).

One of the major areas of difference between the National and State guidelines is the disinfection and turbidity criteria. The NSW guideline for stormwater harvesting has similar criteria to the National guideline for water recycling Phase 1 for wastewater irrigation (NHMRC 2006). The National guideline

Phase 2 for stormwater harvesting is less strict. The reason for this is that levels of faecal-derived microbial indicators and pathogens in stormwater are commonly less than 1% of those found in sewage (NHMRC 2009) and less stringent treatment or exposure control requirements will achieve the same degree of health risk management.

NSW State Government Guidelines

Managing urban stormwater – Harvesting and Reuse published by the NSW Department of Environment and Conservation in 2006 provides guidance on key considerations for future stormwater harvesting and reuse projects based on the experiences of the pilot projects that had been constructed up until that time (DEC 2006). It provides information for planning, project design, operation, maintenance and monitoring and has been used to inform the risk assessment and monitoring regime for the majority of Ku-ring-gai Council's stormwater harvesting systems.

The public health risk management assessment, resulted in Ku-ring-gai's systems focussing heavily on a coarse (e.g. GPT) to medium (sand filter/ rain garden) pre-treatment with access controls including signage, restricted access to any open water and irrigation during unoccupied hours and/or sub-surface irrigation. These approaches were taken to ensure that the systems meet the criteria of Level 2 or 3 systems as listed in Table 1 (DEC 2006). The guidelines identify *E-coli* as the preferred pathogen indicator and recommend that sampling should be done weekly. It should be noted however that monitoring performed by Ku-ring-gai Council was restricted and therefore was less extensive than what is recommended in the DEC 2006 guidelines.

Table 1 NSW guidelines for stormwater quality criteria for public health risk management (Table 6.4, DEC 2006).

Contact Level		Guideline Value
Level 1	Reticulated non-potable residential uses (such as garden watering, toilet flushing, car washing)	*E. coli.* <1cfu/100mL
		Turbidity ≤ 2 NTU
Level 2	Spray or drip irrigation of open spaces, parks and sports grounds (no access controls)	*E. coli.* <10cfu/100mL
	Industrial uses – dust suppression, construction site use (human exposure possible)	Turbidity ≤ 2 NTU
	Ornamental water bodies (no access controls)	
	Fire-fighting	
Level 3	Spray or drip irrigation (controlled access) or subsurface irrigation of open spaces, parks and sports grounds	*E. coli.* <1000cfu/100mL
	Industrial uses – dust suppression, construction site use, process water (no human exposure)	
	Ornamental water bodies (access controls)	

Australian National Guidelines

The National guidelines (NHMRC 2009) provide additional background data and scientific information that is designed to be used to plan and evaluate system risks and performance. A summary of the guideline values is presented in Table 2 (NHMRC 2009).

Table 2 Stormwater treatment criteria for public, open-space irrigation (no access control) — managing health risks (Table 3.3, NHMRC 2009)

Parameter	Stormwater treatment criteria
Disinfection	>1.5 log10 (96%) reduction of viruses and bacteria >0.8 log10 (82%) reduction of protozoan parasites *E. coli* <10 colony forming units (CFU)/100 mL (median)
Turbidity	<25 nephelometric turbidity units (NTU) (median) 100 NTU (95th percentile) provided the disinfection system is designed for such water quality and that, during operation, the disinfection system can maintain an effective dose by using up all disinfectant demand and providing free disinfectant residual and/or provides adequate UV dose even in the presence of elevated turbidity and UV absorbing materials

2.2 Previous water quality monitoring in Ku-ring-gai

Due to limitations in time, budget and available information, Ku-ring-gai has previously been restricted to implementing a largely qualitative risk based assessment, based on the information provided by the NSW guideline document (DEC 2006) and an assessment of the individual projects. The assessments place a great emphasis on reducing risks through preventative planning to minimise the requirement for curative measures in the long run. While the NSW guidelines propose a weekly monitoring regime for stormwater reuse systems (monitoring *E. Coli.),* funding and time restrictions have meant this regime can not be supported. Rather a monthly program was implemented from July to December 2009. Results are presented in Table 3, with samples collected from the irrigation system at each site.

Table 3: E-coli (CFU/100ml) Results of monthly irrigation monitoring (July – December 2009 Water harvesting site quality analysis).

	Lindfield Soldiers Memorial	Edenborough	Barra Brui*
Highest	22	2	4
Lowest	1	1	-
Median	1.5	1	-

* Only one sample was able to be collected during this time, with the storage being inaccessible at other occasions.

The results presented in the Table 3 show that each of the systems broadly meets the Level 2 criteria of the NSW Guidelines and are definitely below the level of 1000/100ml required for Level 3. In all cases but one the water would also comply with the National guidelines for open space irrigation without access control.

These results appear to indicate that there is little cause for concern relating to pathogens in these stormwater harvesting systems. These results also indicate that the simple pre-treatment, access and management controls are sufficient to mitigate against health risks, as identified by council's qualitative pre-construction risk assessment.

It should be noted that the data from Table 3 was gathered on occasions that had relatively low rainfall. The highest readings occurred when there had been only 14.2mm in the 7 days up to and including the sample day. However, previous investigations by the authors have demonstrated that there is a large influx of *E-coli* into stormwater harvesting systems during high rainfall events (Findlay et al 2009) with values as high as 12,000 cfu/100mL recorded. Nevertheless, it was demonstrated that the bacteria appear to die-off to safer levels whilst in storage within days following a rainfall event (Findlay et al 2009). From an irrigation perspective, it would be unusual for the ovals to require watering after such rain events, allowing the die off of pathogens and therefore reducing the health risk. However, this high input of Coliforms during a rainfall event created a concern that there was potential for other pathogens, possibly more hazardous and persistent ones, to also be present.

Having completed a number of systems Ku-ring-gai has undergone a more quantitative risk assessment as outlined in the National guidelines (NHMRC 2009) for the quality of the irrigation water. This assessment has been undertaken to validate those assumptions that have previously been made, and indicate whether any curative measures need to be retrofitted to the systems to minimise risk to public health.

3 METHODS

This paper presents the results of a two part investigation, which involved data collection and then an assessment of risk based on the results.

The first part of the investigation involved collecting water samples to enable parasite and virus analysis to be conducted on water from the stormwater harvesting systems. The samples were collected from either the storage tank or irrigation infrastructure to ensure that the water had already passed through the available treatment. The three longest established systems were included in the sample regime.

These three sample sites include:

- Barra Brui Oval (St Ives)
  - completed in 2005
  - GPT/ Wetland treatment
  - 250 000L below ground metal storage tank
  - Pop-up sprinkler irrigation (automated)
- Edenborough Oval (Lindfield)
  - completed in 2007
  - GPT/ Sand filter treatment
  - 300 000L above ground concrete tank
  - Manual irrigation (QCV for travelling irrigator)
- Lindfield Soldiers Memorial Oval (Lindfield)
  - completed in 2008

- GPT (CDS) treatment
- 500 000L above ground metal storage tank
- Disc filter
- Sub-surface irrigation (automated)

Each site was sampled on 07 June 2010 (Sample A) and 24 June 2010 (Sample B). For Sample A the samples were taken for the storage tank at each site. For Sample B the samples were taken from an irrigation valve/ sprinkler at each site. For Barra Brui and Edenborough, the irrigation is pumped straight from the storage, and as such the samples are considered comparable. At Lindfield Soldiers Memorial there is a disc filter between the tank and the irrigation. Even though the sample events can not be directly compared, the samples were used to gain a broader understanding of the levels of indicator organisms in relation to other pathogens present in the stormwater.

Samples were collected in a 20L Jerry can (provided by council) and microbiological sample bottles provided by Sydney Water analytical services. The Jerry cans were rinsed with a quantity of the subject water prior to formal collection of the sample. Sample A was collected following a large rainfall event (143mm for the 7 days up to and including when the sample was taken) whilst Sample B was collected during a week with significantly less rainfall (20.8mm for the 7 days up to and including when the sample was taken), as demonstrated in Figure 1.

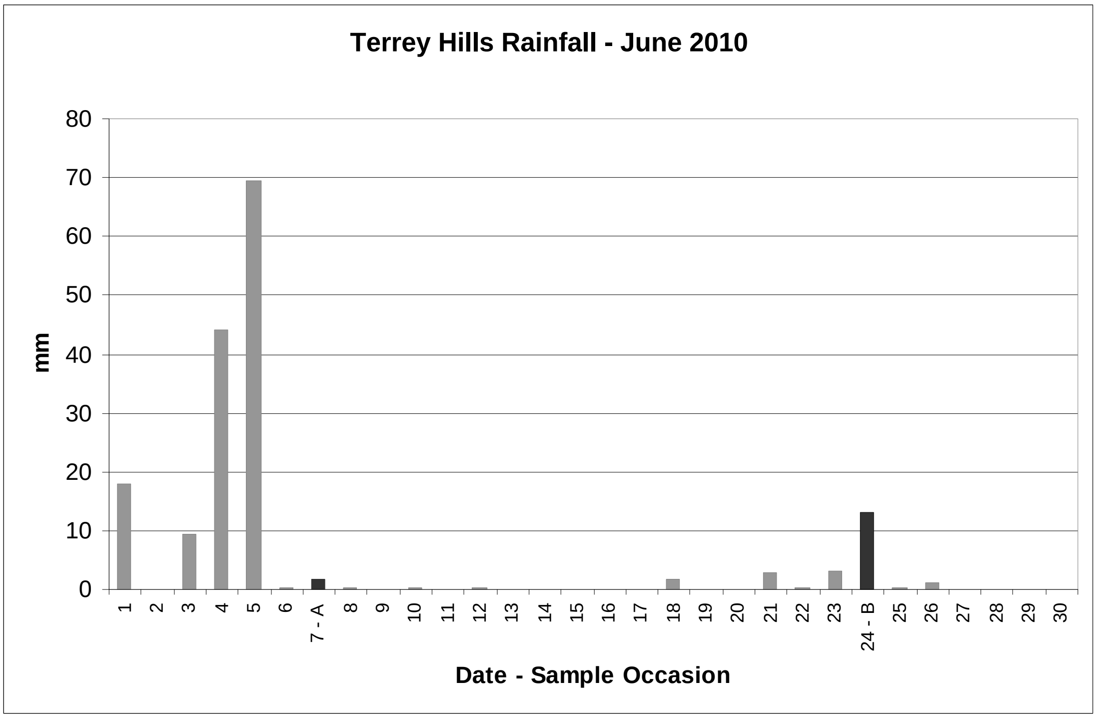

Figure 1. Rainfall (up to 9am) from Terrey Hills AWS (5km north of Ku-ring-gai LGA) for June 2010. Sample occasions A and B are listed in the x-axis identified by the darker bars.

Samples were analysed by Sydney Water monitoring services (NATA accredited) for Total coliforms, *E. Coli*, Enterococci, primary bacteria, Cryptosporidium, Giardia, Rotavirus; Adenovirus; Reovirus and Enterovirus.

The second part of the investigation comprised of a semi-quantitative risk analysis of the pathogens identified by this sampling. This was undertaken to determine how well existing treatment and risk controls are predicted to manage risk to public health.

The microbiological health risk assessment was undertaken using information provided in the Australian national guidelines (NHMRC, 2009). This process involves a quantitative approach which uses the disability adjusted life years (DALY) approach (NHMRC, 2009), which compares the severity of different hazards (pathogens) for any given concentration.

The National guidelines outline the DALY value as the appropriate unit for which to assess health risk as it can:

- *"define the acceptable level of risk to public health*
- *compare impacts from different hazards; for example, those that cause acute impacts (eg a brief episode of diarrhoea) and those that cause chronic impacts (eg arthritis)*
- *ensure that control efforts are directed at hazards with the greatest potential impacts on public health"* (NHMRC, 2009 p57).

Of particular interest to local government authorities is the ability to compare the impacts from different hazards, allowing justifiable prioritisation and mitigation of particular risks.

The acceptable risk to human health outlined by the National guidelines has been set to a level of one-millionth of a DALY (10^{-6}) per person per year. The guidelines indicate that this roughly represents one person in a thousand contracting diarrhoea in one year as a result of a water recycling scheme (NHMRC, 2009).

Using the approach outlined by the National guidelines (NHMRC, 2009), the following factors are considered as part of this assessment:

- *Hazard Identification* – This includes hazardous pathogens likely to be present. In our case we chose the reference pathogens given in the Phase 1 guidelines (*Cryptosporidium and* Rotavirus) in addition to Giardia (a well known pathogen in drinking water) and have measured their concentration during sampling. It should be noted that *E. coli.* is not used as a reference pathogen (as most *E. coli* are non-pathogenic) and is used only as an indicator organism in the guidelines.
    - For this analysis we assessed the residual risk (that which is still present after the treatment). Consequently the data provided from the post treatment sample results are taken as the maximum possible risk.
    - In the guidelines the 95^{th} percentile concentration is used, however due to the restricted data available for the Ku-ring-gai Systems the highest value was used to allow a conservative assessment.
- *Determination of Dose Response* – The values provided in the phase 1 guidelines were used for this assessment.
- *Exposure Assessment* – The default values for "Municipal Irrigation" given in Phase 1 guidelines was used (NHMRC 2006).
- *Risk characterisation* – This is where the exposure assessment and dose response is combined, and as a result the DALY is calculated.

4 RESULTS

4.1 Pathogen analysis

The results of the water quality analysis for pathogens undertaken on the harvested water from Barra Brui (BB), Lindfield Soldiers Memorial (LSM) and Edenborough (Eden) Ovals are presented in Tables 4 and 5. As expected, since these samples were gathered during rainfall events the indicator organism levels are much higher than those gathered during the 6 month analysis (Table 3). Analysis of the data during these high rainfall events provided confidence that a 'worst case' scenario was targeted and results of interest would be obtained. It should be noted that due to the high rainfall, irrigation of these ovals did not occur during this time.

Table 4. Results from the Bacteria Analysis

Site	Total Coliforms (Orgs / 100mL)		*E-coli* (Orgs / 100mL)		Enterococci (CFU/100mL)		Primary bacteria identified (MI15)	
	A 07/06	B 24/06	A 07/06	B 24/06	A 07/06	B 24/06	A 07/06	B 24/06
BB	5500	38	440	2	250	~7	Enterobacter Genus	*Citrobacter youngae*
LSM	5700	3400	370	86	200	~59	*Raoultella terrigena* *Enterobacter cloacae*	*Providencia alcalifaciens/ rustigianii*
Eden	16000	2	2400	<1	~730	<1	*Serratia liquefaciens*	*E coli*

Table 5. Parasites: Results from the Parasite Analysis

Site	Cryptosporidium DAPI positive (10L sample)		Giardia (5L Concentrated)	
	A 07/06	B 24/06	A 07/06	B 24/06
BB	2	2	-	4
LSM	-	-	-	-
Eden	4	1	-	-

The samples from each site were also tested for Rotavirus; Adenovirus; Reovirus and Enterovirus and these all returned negative results.

4.2 DALY Calculations

Sampling at Lindfield Soldiers Memorial Oval did not return any positive results for Cryptosporidium or Giardia. As such the DALY calculations were only completed for Barra Brui and Edenborough Ovals. For Giardia, information on infection probability was derived from Rose et al (1991), while the ratio of illness to infection was conservatively assumed to be 100%. The DALY per case was assumed to be the same for Giardia as for Cryptosporidium (Haagsma et al 2009) Result of the DALY calculations is presented in Table 6.

Table 6. Result of the DALY calculations for Barra Brui and Edenborough

	Barra Brui		**Edenborough**
	Cryptosporidium	Giardia	Cryptosporidium
Organism count/ litre (N) (Maximum result)	0.2	0.4	0.4
DALY/year	**6.19×10^{-7}**	**5.95×10^{-7}**	**1.239×10^{-6}**
Log reduction required to comply with tolerable risk (NHMRC, 2009)	**N/A**	**N/A**	**0.093**

5 DISCUSSION

Results of the water quality investigation showed that despite the high levels of indicator organisms such as Total coliforms, E-coli and enterococci, reference pathogens such as parasites *Cryptosporidium* and Giardia are not detected in significant numbers. For example, ingestion of around 100 oocysts has been shown to be the median infective dose for Cryptosporidium (DuPont et al 1995). The highest number of infective oocysts identified was 4 in a 10L sample of water. As the purpose of this water is for irrigation, it is highly unlikely that a person will manage to consume enough oocysts to result in an occurrence of Cryptosporidiosis. The calculation of DALY/year for *Cryptosporidium* for Edenborough Oval does however indicate that further treatment / management would be required in order to reduce the risk to human health to acceptable levels. A list of indicative exposure reduction provided by on-site preventative measures is included in NHMRC (2006). Here "No public access during irrigation" is given a reduction in exposure to pathogens equivalent to a log reduction of 2. This is well in excess of the required 0.09 and as such the system at Edenborough complies with the intent of current guidelines in terms of exposure to *Cryptosporidium*.

The results from this study show no clear correlation between high readings of *E.coli* and *Cryptosporidium* or Giardia. *Cryptosporidium* was present at Edenborough in both samples while no *E.coli* was detected in the second sample. At Barra Brui, *Cryptosporidium* was detected in both samples at the same level while the *E.coli* count differed significantly between the two samples. This finding support previous investigations that have not been able to find any clear relationship between *E. coli* as an indicator organism and pathogens such as *Cryptosporidium* and Giardia (NHMRC, 2009).

The National guidelines do not provide enough information to calculate DALY/year for Giardia and information had to be obtained from other sources. In any case, given the low annual volume that is assumed to be ingested the risk of contracting illness due to Giardia in reused stormwater is considered low.

As no viruses were detected in any of the samples taken as part of this study, it is not possible to comment on the relationship between *E. coli* and the presence of viruses in stormwater.

Both the NSW (DEC 2006) and National guidelines (NHMRC 2006 & 2009) provide a value for turbidity as turbidity levels can impact on the operation of irrigation infrastructure and the effectiveness of disinfection treatments such as UV radiation. The NSW guidelines for turbidity provides a median of ≤2 (maximum of 5) for level 1 and level 2, no value is listed for level 3 management (Table 1). However, the NHMRC (2009) (Table 2) sets a level of <25 NTU (median) on the basis that there is likely to be significantly lower pathogen levels in stormwater than in recycled water (which is used to derive most of the indicator values). Where a relatively low concentration of pathogens is targeted (such as for the systems in this study) the efficiency of the UV treatment would need to be high to ensure that required reductions are achieved and this may be compromised by NTU levels over 2. Recent test results from Ku-ring-gai's systems have been ranging from 1.8 to 28 NTU in which case it may be more feasible to rely on the access controls and other management strategies that achieve the required log reductions as outlined in (NHRMC 2009) than to rely on UV disinfection.

6 CONCLUSION

Previous sampling of Ku-ring-gai Council's stormwater harvesting schemes has shown that elevated levels of indicator bacteria such as *E-coli* commonly occur following and during rainfall events (Findlay 2009). This data indicates a potential for other hazardous organisms including parasites such as *Cryptosporidium* that prove to be more persistent in the harvesting environment (for instance storage tanks) to be present.

The monitoring undertaken as part of this study suggests that by relying on Faecal coliforms, enterococci and particularly *E-coli* (as tends to be used as the indicator organism) to evaluate the risk to public health, the risk is likely to be overestimated for these systems.

From a practical perspective there exist major limitations to local government and others to undertake a valid testing program for pathogens, most specifically the cost and frequency of comprehensive testing. The catch is to rely on an indicator organism that, as this study has found, is not always a reliable predictor of the health related risks associated with the water. UV treatment could be used to provide a higher security to an alternative water supply, however in many cases effective pre-treatment followed by appropriate access controls would suffice as demonstrated by the DALY calculations undertaken for Edenborough Oval.

In terms of risk management, the data from this study suggests that appropriate management regimes such as irrigating at night and not allowing public access to irrigated areas is most likely sufficient to comply with the intent of current NSW and national guidelines for stormwater reuse without necessitating disinfection.

It is important to note however that the conclusions from this study are only valid for the systems assessed as part of this study and is not necessarily directly transferable to other systems. Furthermore these findings are based on a very limited data set and further investigations are required to confirm these preliminary findings.

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