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Irrigating food crops with stormwater

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Document history and status

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00	25/10/18	Draft report for client review	Belinda Hatt		
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Contents

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1. Introduction

With the use of water approaching, and in some cases exceeding, the limits of sustainability in many locations, stormwater is increasingly being recognised as a viable alternative water source that can reduce the demand on potable water sources. Stormwater harvesting to supply urban water demands has an additional benefit of reducing the impact on urban waterways as the conventional approach to stormwater management is the primary cause of degradation of waterways.

Surface runoff from urban areas is generally of poorer quality than that from natural catchments, with higher concentrations and loads of pollutants (Carpenter et al. 1998, Chocat et al. 2001). Anthropogenic activities such as construction sites, industrial areas, deposition of airborne pollutants, fertilisers from gardens and chemical spills all contribute to stormwater pollution. As a result, there are potential chemical and microbial risks associated with the use of stormwater and these risks are influence by the end use and treatment approach.

The aim of this review was to assess the potential public health risks associated with the use of harvested stormwater to irrigate food crops. This report begins by presenting the typical characteristics of untreated stormwater and the water quality requirements for the irrigation of food crops. Next, it assesses the potential health risks associated with two stormwater harvesting schemes located within the boundaries of Moreland City Council where it is proposed to irrigate food crops with treated stormwater. The potential for uptake of pollutants by food crops irrigated with stormwater is then discussed. Finally, implications for practice and remaining knowledge gaps are highlighted.

2. What are the pollutants of concern in stormwater?

Stormwater is defined as rainfall-runoff generated from all urban surfaces. It commonly contains a range of pollutants that can be detrimental to human and environmental health, including metals, pesticides, pharmaceuticals, endocrine disrupting chemicals, industrial chemicals and pathogens. Although the quality of stormwater is generally higher than that of wastewater (Mitchell et al. 2002), there can be exceptions e.g. hydrocarbons and pesticides. Pollutant concentrations in stormwater are highly variable within and between rainfall-runoff events as well as between catchments.

Table 1 presents a summary of the typical stormwater concentrations of a range of water quality parameters. The characterisation of stormwater quality has historically focussed on pollutants on concern with respect to aquatic ecosystem protection i.e., physicochemical characteristics, nutrients, heavy metals and, to a lesser extent, standard microbial indicators. However, the primary pollutants of concern are different for stormwater harvesting, with greater emphasis on potential public health risks (Table 3).

Table 1. Comparing the typical quality of untreated stormwater with the water quality requirements of selected urban water demands

Constituent	Unit	Untreated urban stormwater [i]	Drinking Water (NHMRC & NRMMC 2004)	Irrigation water (ANZECC/ARMCANZ 2000)	
				Short-term (up to 20 years) trigger values	Long-term (up to 100 years) trigger values
Pathogens – reference species and indicators					
Clostridium perfringens	cfu/100mL	103 - 2748			
Coliforms	cfu/100mL	3,369 - 355,988			
E coli	cfu/100mL	3,835 - 184,382	0		
Enterococci	cfu/100mL	1,621 - 34,465			
Faecal coliforms	cfu/100mL	4,694 - 215,568			
Faecal foliforms	cfu/100mL	0 - 6x10^{5}			
Faecal streptococci	cfu/100mL	3,829 - 70,894			
Protozoa	org/100L				
Somatic coliphages	#/100mL	1,154 - 54,704			
Thermotolerant coliforms	cfu/100mL		0	<10 [f], <1000 [g]	
Total coliforms	MPN/100ml	1x10^{5} - 7.5x10^{5}			
Viruses	org/10,000L				
Metals					
Aluminium	mg/L	0.3 - 2.28	0.2	20	5
Arsenic	mg/L	0.006 - 0.011	0.007	2	0.1
Boron	mg/L	0.08 - 0.17	4	1.0 – 2.0 [h]	0.5
Cadmium	mg/L	0.0015 - 0.0606	2	0.05	0.01
Calcium	mg/L	0.054 - 14.845			
Chromium	mg/L	0.002 - 0.017		1	0.1
Chromium (hexavalent)	mg/L	0.0055 - 0.11	0.05		
Copper	mg/L	0 - 0.141	2, 1	5	0.2
Iron	mg/L	0.08 - 5.1	0.3	10	0.2
Lead	mg/L	0 - 0.162	0.01	5	2

Constituent	Unit	Untreated urban stormwater[i]	Drinking Water (NHMRC & NRMMC 2004)	Irrigation water (ANZECC/ARMCANZ 2000)	
				Short-term (up to 20 years) trigger values	Long-term (up to 100 years) trigger values
Magnesium	mg/L	3 - 15			
Manganese	mg/L	0.037 - 0.197	0.5, 0.1	10	0.2
Mercury	mg/L	0.08 - 0.411		0.002	0.002
Nickel	mg/L	0.004 - 0.017	0.02	2	0.2
Potassium	mg/L	1.8 - 21.4			
Zinc	mg/L	0.02 - 0.57	3	5	2
Micro-pollutants					
Anionic Surfactants	mg/L	0.2 - 0.45			
Chlorine	mg/L		5		
Cyanide	mg/L		0.08		
Fluoride	mg/L			2	1
Oil and grease	mg/L	3.43 - 28.25			
Polycycle aromatic hydrocarbons	ug/L	0.017 – 4.4	0.01		
Selenium	mg/L			0.05	0.02
Sulphate	mg/L	8 - 505	250		
Uranium	mg/L			0.1	0.01
Nutrients					
Filterable reactive phosphorus	mg/L	0.05 - 2.037			
Nitrate (NO_3^-)	mg/L	0.1 - 6.2	50		
Nitrite	mg/L	0.1 - 0.3	3		
Oxidised nitrogen	mg/L	0.132 - 1.523			
Total dissolved nitrogen	mg/L	0.68 - 8.22			
Total kjeldahl nitrogen	mg/L	0.6 - 8.82			
Total nitrogen	mg/L	0.4 - 7.46		21-125[a]	5
Total organic nitrogen	mg/L	0.16 - 1.874			
Total phosphorus	mg/L	0.034 - 1.261		0.8-12[a]	0.05[j]
Pathogens					
Campylobacter	cfu/100mL	1 - 7.02			
Cryptosporidium	cfu/100mL	12 - 546			
Giardia	cfu/100mL	0.12 - 5.55			
Physico-chemical indicators					
Ammonia	mg/L	0.02 - 3.281	0.5		
Bicarbonate alkalinity as CaCO3	mg/L	29.99 - 40.97		<60	<60
Biochemical oxygen demand	mg/L	6.56 - 25			
Chemical oxygen demand	mg/L	32.9 - 88.72			

Constituent	Unit	Untreated urban stormwater[i]	Drinking Water (NHMRC & NRMMC 2004)	Irrigation water (ANZECC/ARMCANZ 2000)	
				Short-term (up to 20 years) trigger values	Long-term (up to 100 years) trigger values
Chloride	mg/L	9.75 - 13.2	250	175 – 230 [h]	175 – 230 [h]
Electrical conductivity	EC (dS/m)	0.074 – 1.81		<1.9 (Table 2)	<1.9 (Table 2)
pH		5.5 - 7.27		6 - 9	6 - 9
Sodium	mg/L	6.58 - 15.72	180	115 – 230 [h]	115 – 230 [h]
Suspended solids	mg/L	5 - 254.49			
Total dissolved solids	mg/L	44 - 169.6	500		
Total organic carbon	mg/L	11.99 - 22.8			
Turbidity	NTU	7.98 - 127.79	5, <1[e]		

[a] Requires site-specific assessment (section 9.2.6 of ANZECC guidelines)

[b] After minimum contact time of 30 minutes

[c] Where there is significant risk of off-site movement of the water

[d] To minimise bioclogging of irrigation equipment only

[e] For effective disinfection

[f] Irrigation of raw human food crops in direct contact with irrigation water (ANZECC/ARMCANZ 2000)

[g] Irrigation of raw human food crops not in direct contact with irrigation water (ANZECC/ARMCANZ 2000)

[h] Moderately sensitive agricultural crops

[i] References: (Dillon & Pavelic 1996, Leeming et al. 1998, Brisbane City Council 2004, Deletic & Fletcher 2004, Fletcher et al. 2004, Flower 2004, Fuchs 2005, Duncan 2006, NRMMC et al. 2009)

[j] To minimise bioclogging of irrigation equipment only

Table 2. Tolerance of plants to salinity in irrigation water for crops growing in sand (adapted from ANZECC/ARMCANZ 2000)

Common Name	EC threshold (dS/m)
Fruits	
Orange	2.9
Grape	3.3
Apple	2
Peach	4.7

Common Name	EC threshold (dS/m)
Vegetables	
Zucchini	7.3
Beetroot	6.5
Broccoli	4.9
Cucumber	4.2
Pea	3.2
Tomato	3.5
Potato	3.2
Capsicum	2.8
Lettuce	2.7
Onion	2.3
Eggplant	3.2
Bean	1.9
Carrot	2.2

Table 3. Pollutants of concern for stormwater harvesting and aquatic ecosystem protection, listed in order of decreasing importance.

Stormwater harvesting	Aquatic ecosystem protection
Faecal pathogens	Nutrients
Micro-pollutants	Heavy metals
Heavy metals	Sediment
Hydrocarbons	Oxygen demanding
Nutrients	Hydrocarbons
Sediment	Micro-pollutants
Oxygen demanding	Gross pollutants
Gross pollutants	Faecal pathogens

To address the paucity of data on pollutants of concern from a public health perspective, the Urban Water Security Research Alliance and the Cooperative Research Centre for Water Sensitive Cities (CRC WSC) undertook a water quality sampling campaign to characterise the chemical and microbial quality of stormwater (Sidhu et al. 2012). Ten locations across Melbourne, Sydney, Brisbane and Perth were included in the study, each of which varied in terms of catchment size, age, land-use(s) and climate. Concentrations of a range of pollutants were quantified and compared to the *Australian Guidelines for Water Recycling: Augmentation of Drinking Water Supplies* (AWRG-ADWS, EPHC et al. 2008). In addition, chemical (toxicity) and pathogen risks were assessed. Importantly, this study measured both reference (actual) pathogens and standard microbial indicators, the latter of which tends to be poorly correlated to reference pathogens. This database is the first and most comprehensive Australian stormwater quality database on pollutants of concern from a stormwater harvesting perspective. The findings of this study can be summarised as follows (Sidhu et al. 2012):

- **Metals** such as lead, nickel, cadmium and mercury were often detected in stormwater at concentrations well above public health standards. Iron and aluminium were also frequently detected, although these metals are more concerning from an aesthetic, rather than a public health, perspective.

- **Pesticides**, including diuron, MCPA, 2,4-D, simazine and triclopyr were found in more than 50% of samples however concentrations were generally low and less than 10% of samples exceeded public health standards.

- **Pharmaceuticals and personal care products** – stormwater is likely to contain commonly used pharmaceuticals such as caffeine, acesulfame-K (artificial sweetener), paracetamol and salicylic acid. Concentrations of pharmaceuticals were below public health standards except for caffeine, which was found to exceed standards by up to a factor of 20. Prescription drugs were detected in approximately 10-15% of the samples analysed. Of the 57 pharmaceuticals and personal care product analysed, all but caffeine were present in negligible concentrations relative to the AWRG-ADWS guidelines.

- **Endocrine-disrupting chemicals**, including steroidal hormones, were generally absent or found in low concentrations. Mestranol, an active ingredient in contraceptive pills, was an exception to this trend and was found to exceed public health standards in nearly a third of samples.

- **Industrial chemicals** associated with polycarbonate plastics and epoxy resins were frequently detected in stormwater but at concentrations well below public health standards.

- A broad suite of **pathogens** was found in stormwater. Further, the widespread detection of human-specific microbial and chemical markers (e.g. caffeine) suggests ubiquitous contamination of stormwater by sewage. This means that there is potentially significant human faecal contamination, instead of animal contamination, which has much higher implications for public health.

The study concluded that there are potential public health risks due to the presence of human faecal contamination but that chemicals are less of a health concern, with the exception of metals. This is consistent with the Australian Guidelines for Water Recycling (NRMMC et al. 2006), which notes that long-term exposure to low levels of chemicals is an emerging area of concern. Pollution of stormwater with these contaminants is sufficiently severe to require treatment, particularly if high human exposure scenarios are contemplated (Sidhu et al. 2012). Based on the findings of this study, this review will primarily focus on the potential risks associated with pathogens and heavy metals from here on in.

2.1 Exposure pathways for stormwater harvesting schemes for the irrigation of food crops

There are two potential human exposure pathways for schemes where harvested stormwater is used to irrigate food crops:

- Contact with harvested stormwater e.g. people using the surrounding public open space (e.g. contact with stored stormwater, spray drifts), occupational exposure for maintenance staff

- Consumption of produce that has come into contact with contaminants in harvested stormwater and / or receiving soils.

The main risk to public health is via contact with harvested stormwater but it is noted that the risk from pathogens is greater for food crops that are not cooked or processed prior to consumption e.g. salad crops.

3. What are the water quality requirements for irrigation of food crops?

The water quality requirements for the irrigation of food crops are stricter than those for general irrigation because the level of human exposure is higher, particularly for crops that may be consumed raw or unprocessed. In Australia, the current guideline specific to stormwater reuse is the *Australian Guidelines for Water Recycling: Stormwater Harvesting and Reuse* (AGWR-SHR, NRMMC et al. 2009). This describes a standard approach that can be used to manage the health and environmental risks associated with a stormwater harvesting scheme for a range of end-use applications, including irrigation of food crops.

The guidelines specify tolerable pathogen levels for use of harvested stormwater to irrigate food crops (Table 4). Consistent with the observations of Sidhu et al. (2012), the guidelines note that chemical hazards in stormwater would ordinarily be far below acutely hazardous concentrations for sporadic, small-volume exposures. As a result, the exposure controls required to adequately manage microbial health risks from low-exposure uses of recycled wastewater are considered adequate to manage chemical health risks for the equivalent uses of reused stormwater (NRMMC et al. 2009) and thus tolerable concentrations are not provided for other water quality parameters. As a point of reference, Table 1 compares the quality of untreated stormwater to the water quality requirements for drinking and irrigation water and it can be seen that concentrations of most pollutants are generally well below these guidelines.

Table 4. Tolerable pathogen levels and required reductions for stormwater reuse for the irrigation of commercial food crops (exposure = 490 mL/person/year, NRMMC et al. 2009)

Reference pathogen	Tolerable concentration (infectious units per L)	Required reduction	
Rotavirus	0.0051	99.5%	2.3 log
Cryptosporidium	0.016	98.2%	1.7 log
Campylobacter jejuni	0.078	99.5%	2.3 log

3.1 Exposure controls for stormwater harvesting schemes

Some type of exposure control is required for most stormwater harvesting schemes, depending on the human exposure scenario. It is also recommended that sewage contamination should be assumed for all stormwater harvesting schemes, given the widespread prevalence of human pathogens in stormwater (Sidhu et al. 2012). The type of control may involve eliminating sources of contamination (e.g. sewage – stormwater cross connections), treatment after collection, or access control. For schemes where harvested stormwater is used to irrigate food crops, exposure controls may consider preventing direct contact with stormwater during the collection, treatment, storage and irrigation stages as well as preventing bioaccumulation of contaminants. This could include underground / closed storages, irrigation methods that provide a physical separation of water from people and produce (e.g. sub-surface irrigation, irrigation at night) and appropriate signage, in addition to suitable treatment processes.

Treatment targets and the recommended treatment type for irrigation of food crops are presented in Table 5. The effectiveness of other relevant treatment types and on-site control measures are summarised in Table 6 and Table 7, respectively. It can be seen that there are multiple exposure controls that can achieve the necessary treatment targets. The guidelines note that there is limited information on the effectiveness of the estimates of microbial hazard reductions achieved by the on-site control measures presented in Table 7. Where this type of preventive measure is applied, it is therefore essential that the application is supported by education of users and monitored using surveillance and auditing (NRMMC et al. 2009).

Table 5. Treatment targets and recommended controls for irrigation of food crops (NRMMC et al. 2009)

Use	Pathogen type	Log reduction targets	Recommended treatment	Log reduction achieved	Any extra criteria to be tested?
Irrigation of commercial food crops[a]	Virus Protozoa Bacteria	2.4 log 1.9 log 2.4 log	Membrane filtration and disinfection	>2.5	Turbidity[b]: < 25NTU (max) <10NTU (95th percentile) <2NTU (target) *E.coli* <1/100mL

[a] Exposure = 490 mL/person/year

[b] for effective disinfection

Table 6. Indicative $\log_{10}$ reductions of reference pathogens in wastewater after different treatments that are relevant to stormwater (NRMMC et al. 2009)

Treatment	Indicative log reductions		
	Viruses	Protozoa	Bacterial pathogens
Dual media filtration with coagulation	0.5 – 3.0	1.5 – 2.5	0 – 1.0
Membrane filtration	2.5 – >6.0	>6.0	3.5 – >6.0
Reverse osmosis	>6.0	>6.0	>6.0
Chlorination	1.0 – 3.0	0 – 0.5	2.0 – 6.0
Ozonation	3.0 – 6.0	-	2.0 – 6.0
Ultra-violet	>1.0 adenovirus >3.0 enterovirus, rotavirus	>3.0	2.0 – >4.0 *Campylobacter* 3.0 – 4.0

Table 7. Indicative exposure reductions provided by on-site preventative measures relevant to irrigation of food crops (NRMMC et al. 2009)

Control measure	Reduction in exposure to pathogens
Cooking or processing of produce	5-6 log
Removal of skin from produce before consumption	2 log
Drip irrigation of crops	2 log
Drip irrigation of crops with limited to no ground contact (e.g. tomatoes, capsicums)	3 log
Drip irrigation of crops with no ground contact (e.g. apples, apricots, grapes)	5 log
Sub-surface irrigation of above-ground crops	4 log
Withholding periods – produce (decay rate)	0.5 log/day
No public access during irrigation	2 log
No public access during irrigation and limited public access following irrigation	3 log

Large fluctuations in the timing, quality and quantity of stormwater have been shown to impact the pollutant removal performance of conventional stormwater treatment systems (e.g. wetlands, ponds, raingardens) because these systems experience both wet (during highly variable rainfall / runoff events) and dry periods (where there can be no inflow for several weeks). Given this uncertainty, the AWRG-SHR recommends taking a conservative approach and assume that conventional stormwater treatment measures do not reduce the levels of reference pathogens. Nevertheless, since the publication of those guidelines, considerable effort has been devoted to redesigning stormwater treatment systems for effective pathogen removal. The results of this work are summarised below. For greater certainty, a case-by-case validation of the treatment efficacy of stormwater treatment systems would be required (Sidhu et al. 2012).

Raingardens

Studies on biofilters and pathogen removal have reported high pathogen removal rates (Bratieres et al. 2008, Li et al. 2012). Bratieres et al. (2008) investigated removal of three pathogenic indicators (*Escherichia coli (E.coli)*, *clostridium perfringens* (*C. perfringens)* and *F-RNA coliphages)* and reported removal rates above 80% with *C. perfringens* being removed at the highest rates of more than 99%. The removal of pathogens in biofilter systems has been found to be affected by wet and dry conditions. *E.coli* was found to have lower survival rates in soils following dry weather (Tom et al. 2013). It was suggested that this may be due to several factors, including competition and predation by other microorganisms as well as desiccation (Beuchat 2002, Gagliardi & Karns 2002, Tom et al. 2013). However, antecedent dry periods can also negatively affect pathogen removal as desiccation of the filter media can result in the development of macropores and preferential flow paths which may decrease the filtration capacity of biofilter media (Bratieres et al. 2008, Li et al. 2012). Removal of *E.coli* has been found to be lower following a dry period due to decreased straining (Bratieres et al. 2008, Chandrasena et al. 2012, Li et al. 2012). The addition of a submerged zone (internal water storage) has been found to improve the removal rates of *E.coli* after dry periods, presumably because this internal water storage buffers against drying (Bratieres et al. 2008, Li et al. 2012).

Studies of heavy metal removal by biofiltration have demonstrated high heavy metal removal with up to 98% removal of lead (Pb) and zinc (Zn) (Bratieres et al. 2008, Read et al. 2008). Of the removal processes that occur in a biofilter, mechanical straining by the filter media plays the most important role in the removal of heavy metals. Studies have shown that heavy metals are primarily captured within the top 10cm of the filter media (Hatt et al. 2007, Hatt et al. 2008, Li & Davis 2008). Further, it has been shown that metals accumulated in the filter media have relatively low mobility and largely in environmentally inaccessible forms (Jones & Davis 2012), i.e. once metals have been captured they are unlikely to be remobilised.

Ponds and wetlands

Constructed wetlands and wet ponds (i.e. treatment systems that have a permanent body of water) have been shown to be the most reliable treatment measures for reduction of indicator bacteria. The monitoring data indicates that a constructed wetland or pond designed to achieve a reasonable reduction in the loads of conventional stormwater pollutants is likely to achieve an E. coli reduction of 0.5–1.0 log (68–90%). Farrell and Scheckenberger (2003) and the Stormwater Assessment Monitoring and Performance Program (2005) identified variable performance from ponds and wetlands, with an average E. coli retention of 90%.

3.2 Moreland City Council stormwater harvesting schemes

There are two existing or planned stormwater harvesting schemes within the boundaries of Moreland City Council where it is proposed to use treated stormwater to irrigate food crops:

- Sheils Reserve, Brunswick, which is going to be redeveloped and it is proposed to use treated stormwater to irrigate a community orchard; and
- Mutton Reserve, Fawkner, where there is an existing stormwater harvesting system and there is interest in using treated stormwater to irrigate vegetable crops

To assess the potential health risks of these stormwater harvesting schemes, the indicative effectiveness of each scheme's exposure controls are listed in Table 8. As shown in Table 5, the target treatment is at least a

2.5 log reduction, although it is noted that this guideline value is for irrigation of commercial food crops where the exposure to irrigation water has been calculated as 490 mL/person/year. This is the most applicable end use in the AWRG-SHR but it is likely that the level of exposure associated with the Sheils Reserve and Mutton Reserve schemes will be far lower than 490 mL/person/year. This target treatment could therefore be considered very conservative.

Table 8. Indicative effectiveness of exposure controls for two stormwater harvesting schemes

Stormwater harvesting scheme	Exposure control	Indicative reduction in exposure to pathogens
Sheils Reserve	Pond AND	0.5 - 1.0 log
	Overland (above ground) irrigation of crops with no ground contact OR	0.5 - 3 log[a]
	Sub-surface irrigation of above ground crops (orchard)	4 log
	TOTAL	1 - 5 log
Mutton Reserve	Gross pollutant trap AND	0
	Tank AND	ID[b]
	Raingarden AND	0.7 - 1.7 log[c]
	Tank AND	ID[b]
	UV disinfection	>1.0
	TOTAL	1.7 - >2.7 log

[a] If combined with one of the following control measures: withholding periods – produce (decay rate): 0.5 log/day; no public access during irrigation and limited contact after: 3 log
[b] ID – insufficient data
[c] (Chandrasena et al. 2017)

Sheils Reserve

The exposure controls planned for the Sheils Reserve scheme are expected to reduce potential health risks to acceptable levels and this is largely achieved by the physical separation of the irrigation water and the edible crop. However, as noted previously, there is limited information on the effectiveness of on-site controls, therefore it is recommended that educational signage is installed at the reserve. Whilst the guidelines recommend undertaking monitoring, given that the treatment target is likely to be very conservative, monitoring may not be required.

Mutton Reserve

It is somewhat surprising that, despite the Mutton Reserve stormwater treatment train containing more stages than what is proposed for Sheils Reserve, the expected reduction in pathogens at Mutton Reserve is lower. However, as noted above, this is in part due to the uncertain pathogen removal performance of stormwater treatment measures. Nevertheless, it is expected that health risks would be sufficiently mitigated in light of the following considerations:

- Desiccation of the raingarden filter media during extended dry periods can result in a flush of turbid effluent upon rewetting[1], which would reduce the efficacy of the UV disinfection unit. Since this system

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[1] Following some storm events, turbidity and often levels of organics in stormwater are too high for disinfection without some form of pre-treatment. Both can interfere with disinfection through effects such as physical shielding by turbidity and through UV or oxidant absorption and reaction by organics. Therefore, if it is intented to use stormwater for relatively high exposure uses, one of the key treatment targets is reducing turbidity, and to a lesser extent, organics. (NRMMC, EPHC and NHMRC (2009). Australian Guidelines for Water Recycling:

has an internal water storage to protect against extended drying as well as pumped (controlled) inflows, it is expected that the system would not experience severe drying. Nevertheless, it is recommended that water is pumped into the raingarden on a weekly – fortnightly basis during extended dry periods.

- Tank configuration has been shown to affect the quality of water because it influences the extent to which resuspension of accumulated sediment occurs (Magyar et al. 2011). It is unclear from the schematic just how the inlets and outlets are arranged at Mutton Reserve but it is recommended that tanks have a side inlet and a conical base, that accumulated sediment is regularly cleaned out, and that tank water not be used during or immediately following a rainfall event (Magyar et al. 2011).
- The gross pollutant trap is not expected to provide any treatment of metals or pathogens. Provided inlets to and outlets from tanks are sealed and light cannot enter the tank, it is expected that pathogen levels would not increase in the tanks. Rather, some dieback would occur.
- Additional reductions in pathogens could be achieved through the use of on-site controls e.g. drip irrigation, crop type (fruiting / leafy rather than root vegetables) and withholding periods (Table 7).

Managing Health and Environmental Risks (Phase 2) - Stormwater Harvesting and Reuse, Natural Resource Managment Ministerial Council, Environment Protection and Heritage Council, National Health and Medical Research Council.)

4. Will pollutants accumulate in the edible parts of food crops?

Numerous studies have shown that food crops irrigated with untreated wastewater or grown in contaminated soil (e.g. near a mining site) are at risk of containing excessively high levels of contaminants, however there is limited equivalent knowledge for stormwater systems. This section examines the potential risks of the key stormwater pollutants, namely pathogens and heavy metals, translocating to and accumulating in the edible parts of food crops. It draws on and contains excerpts of a literature review conducted by Kay Ng, a PhD candidate at Monash University. To the best of the author's knowledge, there are no studies on the potential for accumulation of pollutants in the edible parts of orchard trees. There are studies of orchard trees grown in contaminated soils, however the focus of these studies is on toxicity to the orchard trees themselves. It is thus inferred that the risk of contamination of the edible parts of orchard trees is negligible because i) there is no direct contact between the produce and irrigation water and ii) the mass of orchard trees relative to level of pollutants in stormwater is so large that any uptake by orchard trees is heavily "diluted". The discussion below is therefore specific to the risk of pollutant accumulation in vegetable crops. It is noted that all studies specific to stormwater investigated the risks associated with the use of **untreated** stormwater, with the exception of one study. The result of these studies are included as they represent the maximum risk.

4.1 Pathogens

Pathogen contamination of food crops can occur via external or internal contamination (Warriner 2003). Researchers have found that pathogen persistence in soils and plants is affected by a number of factors, including external factors such as pH, soil type, humidity and temperature (Beuchat 2002, Brandl & Mandrell 2002, Gagliardi & Karns 2002, Harapas et al. 2010), microbial community composition and the presence of competition or commensalism (Beuchat 2002, Gagliardi & Karns 2002, Hora et al. 2005, Cooley et al. 2006, Harapas et al. 2010), the type of plant (Takeuchi & Frank 2000, Islam et al. 2005, Harapas et al. 2010) and the presence of injury or damage to plants which can affect the extent of internalization of pathogens (Hora et al. 2005, Erickson et al. 2010, Harapas et al. 2010, Tom et al. Submitted). The potential for internalization of pathogens is perhaps of greatest concern with regards to food production because of the risk of pathogen persistence even after washing with chlorine (Behrsing et al. 2000, Takeuchi & Frank 2000, Solomon et al. 2002a, Warriner et al. 2003). This presents extra risks in crops that can be eaten raw.

Internalization of pathogens into vegetable crops increases the chances of pathogen survival because, once internalized, the pathogens are protected from UV light and the risk of desiccation, both of which have been identified as major causes of elimination of pathogens (Bell 1976, O'brien & Lindow 1989, Harapas et al. 2010). Internalization of pathogens in crops can occur via multiple pathways, including transportation of pathogens through the root system, movement of pathogens through plant apertures as well as through damaged tissue (Solomon et al. 2002b, Bernstein et al. 2007, Ge et al. 2013). Internalization of pathogens through damaged tissue is considered the main pathway as it creates new entry points into the plant while providing an increased source of nutrients for the survival of these pathogens and the potential formation of biofilm that provides additional protection (Takeuchi & Frank 2000, Erickson et al. 2010, Harapas et al. 2010, Tom et al. Submitted).

The only known study that investigated the use of treated stormwater to irrigate food crops was conducted by McCarthy et al (2011). That study tested the effectiveness of two different filtration systems and found no differences in microorganism quality in root and leafy vegetables irrigated with treated stormwater compared to those irrigated with mains water.

4.2 Heavy metals

Contamination of plants by heavy metals can occur through the uptake of metals from the soil or water through the roots or via atmospheric deposition and subsequent adsorption (Lagerwerff 1971, Srinivas et al. 2009, Nabulo et al. 2010). With increasing concerns over the health risks of consumption of heavy metal contaminated crops, there have been an increasing number of studies conducted to identify the levels of heavy metals in vegetable crops irrigated with untreated wastewater or grown in contaminated soils in the past 30 years (Srinivas et al. 2009).

Some metals such as Cu, Zn and Mn are essential trace elements required for various physiological processes, however other metals such as Cd, Pb and Hg are toxic to humans (World Health Organization 1996). Vegetables have been demonstrated to be the main dietary source of these (Cobb et al. 2000) metals for humans; with the exception of zinc and copper, the dietary intake of chromium, manganese, nickel and cadmium largely originates from vegetable consumption (World Health Organization 1996). For example, 50-70% of cadmium consumed originates from vegetables (Ryan et al. 1982, Wagner 1993, World Health Organization 1996, Järup 2003). With the potential for toxicity as a result of overconsumption of some of these metals, it is no surprise that metal contamination of vegetables is gaining increasing attention.

While there are numerous studies on hyperaccumulators and heavy metal accumulation in vegetables grown on contaminated soils or vegetables irrigated with wastewater, studies on metal uptake by food crops irrigated with stormwater are few. Tom et al (2014) studied the extent of metal contamination in vegetable crops irrigated with untreated stormwater under short- and long-term conditions. They created artificially aged gardens to simulate irrigation with raw stormwater over zero, five and ten years. They tested crops that represented three vegetable groups – legume (French bean), leafy (kale) and root (beetroot). Of the five metals tested (Cd, Cr, Pb, Cu and Zn), accumulation of Pb was the most marked sign of contamination, with 6/9 French bean and 7/9 beetroot samples breaching Australia’s food safety standards. Metal concentrations increased with the effective age of the garden but its rate of increase did not match the rate of increase in the soil. In a related series of laboratory studies, Ng et al (2018, submitted) investigated the potential to grow vegetable crops in raingardens, thereby achieving water treatment and food production with one system. They showed that the greatest risks are associated with root vegetables, where the edible part of the plant is in direct contact with stormwater as well as the upper layers of the filter media, where the majority of heavy metals accumulate. Nevertheless, these studies suggest that irrigation of food crops with untreated stormwater is feasible as long as appropriate crops are selected and media are frequently turned over. The inference is that there is little chance of problematic accumulation of pathogens or heavy metals occurring in food crops irrigated with treated stormwater, provided the appropriate exposure controls are in place. This is supported by a local study of vegetables irrigated with treated stormwater, which found that concentrations of nine metals (Al, Cd, Cr, Cu, Fe, Pb, Mn, Ni and Zn) in root and leafy vegetables were similar to those irrigated with mains water (McCarthy et al. 2011). All metal concentrations were below the values set by the *Australia and New Zealand Food Standards Code* (ANSTAT 2010), with the exception of Pb. Concentrations of Pb exceeded the guideline regardless of the irrigation water, and it was hypothesised that was due to elevated soil Pb levels at the study site, a former tip site.

5. Conclusions and recommendations for practice

This review investigated the typical water quality characteristics of stormwater and found that, while stormwater is generally of a higher quality than wastewater, it commonly contains a wide range of pollutants that can be detrimental to human and environmental health, including metals, pesticides, pharmaceuticals, endocrine disrupting chemicals, industrial chemicals and pathogens. The main risk to public health is due to the presence of pathogens, with chemical hazards being less of a health concern.

For stormwater harvesting schemes involving the irrigation of food crops, there are two potential human exposure pathways: i) via contact with harvested stormwater and ii) via consumption of produce that has come into contact with contaminants in harvested stormwater and / or receiving soils. The main risk to public health is from contact with harvested stormwater but the risk from consumption of produce increases for raw food crops. Some sort exposure control is necessary and this could include treatment after collection and / or access control.

The AWRG-SHR recommends membrane filtration and disinfection for stormwater harvested schemes involving irrigation of food crops. However, there are other suitable treatment types and on-site control measures that can sufficiently mitigate public health risks. This includes conventional water treatment processes, irrigation methods that physically separate produce and people from irrigation water, and public access controls. Combinations of two or more of these options are possible.

Monitoring Requirements

The *Australian Guidelines for Water Recycling* recommend undertaking water quality monitoring of stormwater harvesting schemes and guidance is given in Chapter 5 of the Phase 1 guidelines (NRMMC et al. 2006). Given that the exposure levels associated with the Sheils Reserve and Mutton Reserve stormwater harvesting systems are likely to be far lower than those on which the treatment targets are based, it is considered that the public health risk associated with these systems is very low. Further, in the case of Sheils Reserve, the proposed irrigation method provides physical separation of produce from the irrigation water. The main risk is therefore from direct contact with stormwater in either the pond or the swale and this could be managed with appropriate signage. Periodic monitoring of post-treatment water quality and contamination of vegetable crops at Mutton Reserve should be considered, as well as clearly educating consumers about the need to wash produce and / or cook it prior to consumption.

Conventional stormwater treatment systems (e.g. wetlands, ponds, raingardens) have the potential to effectively treat stormwater, however their treatment reliability is affected by large fluctuations in the timing, quality and quantity of stormwater. As such, the AWRG-SHR recommends assuming that these systems do not reduce the level of pathogens in stormwater. For greater certainty, a case-by-case validation of the treatment efficacy would be required.

Other considerations

- Contamination of produce via atmospheric deposition is possible, particularly for Shiels Reserve, which is adjacent to a major road. The risk of this occurring is uncertain but it may be that the orchard tree canopy cover sufficiently protects produce from problematic atmospheric deposition. Further consideration of this is recommended.

- Hazardous events in the catchment of a stormwater harvesting system are possible and this may result in system failure. Examples of potential hazardous events include (EPHC et al. 2008):

  - Chemical use in catchment areas (e.g. use of fertilisers and pesticides)

  - Sewage overflows and septic system discharges

  - Entry of livestock waste

  - Climatic and seasonal variations (e.g. heavy rainfall, drought)

  - Industrial discharges

  - Major fires (firefighting chemicals), natural disasters, sabotage

  - Accidental spills or discharges

  - Leaching from existing or historical waste-disposal (e.g. landfill) or mining sites, and contaminated sites and hazardous wastes

  - Road washing

  Prevention of hazardous events is not possible, stormwater harvesting schemes should have a mechanism for responding to hazardous events. This mechanism could include diversion of contaminated influent around a stormwater harvesting scheme or temporary detention prior to discharge (e.g. holding tanks that can be pumped out or diverted to trade waste).

- Stormwater is generally high in nutrients (nitrogen and phosphorus) and algal blooms in open storages are possible under certain circumstances. Appropriate management strategies include source control, treatment, turbidity management and restriction of light sources. Warning signage and access restrictions are also suitable, should an algal bloom occur (NRMMC et al. 2009).

- Public perception of risks is important and there is often a lack of acceptance of the use of harvested stormwater for end-uses that have minimal human contact (e.g. toilet flushing, irrigation of non-food crops). Appropriate educational material and signage to improve community awareness of water issues and build trust in the safety of irrigating food crops with stormwater may be required.

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