Overview of Public Health & Environmental Aspects of Recycled Water - II

Rudi Regel

Wastewater Design & Standards
SA Water

Government of South Australia

SA Water

OVERVIEW

PART A Recap recycled water framework, key concepts, terminology & Bolivar system analysis

PART B Consolidation of recycled water public health aspects

PART C Recycled water environmental aspects

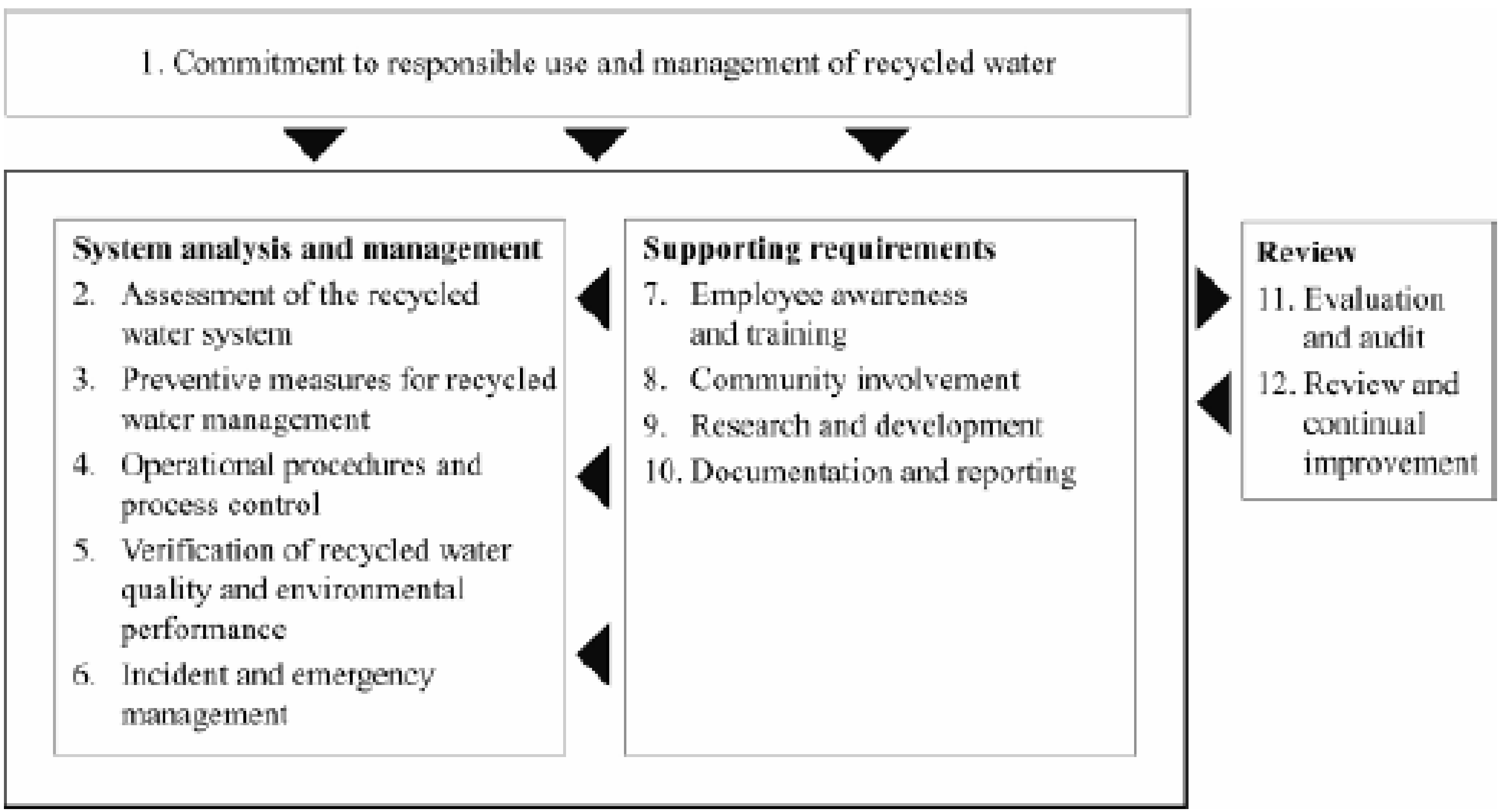
PART D Aquifer aspects

PART A
Recap of recycled water framework, key concepts, terminology, & Bolivar system analysis

Wednesday, 13 Jan 2016

Recap - The "framework" for management of water quality & use

Figure 1.1 Elements of the framework for management of recycled water quality and use



Recap - key concepts & terminology

- Hazard
- Hazardous event
- Pathogen Log Reduction Value (LRV)
- Preventive measure
- Critical control point (CCP)
- Multiple-barrier
- Risk management

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Bolivar system analysis & management (element 2)

1. Define Bolivar system configuration (current)
2. Source of recycled water, intended uses, receiving environments & routes of exposure (current & considering MAR)
3. Recycled water system components (current & considering MAR)
4. Assessment of water quality data & available information
5. Hazard identification (for human health, environment)

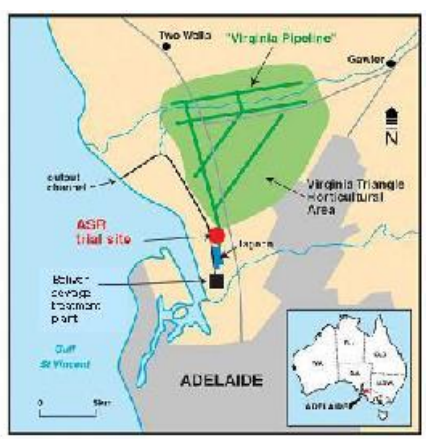

Figure 2 Location of Bolivar ASR trial site near the Northern Adelaide Plains horticultural area (from Barry *et al.*, 2009).

Bolivar system configuration

- ***Current:*** Treat sewage via the Bolivar WWTP & RWTP & it gets distributed via the VPS distribution network to growers & commercial food crops are grown.
- ***Research on Managed Aquifer Recharge:*** Bolivar Aquifer Storage & Recovery whereby recycled water was injected & recovered from the confined tertiary 2 limestone aquifer

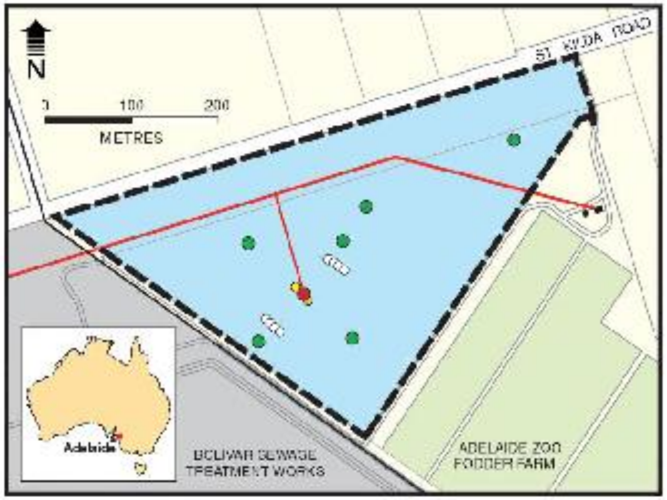

Figure 3 Location of wells and piezometers at the Bolivar site. The red dot represents the T2 ASR production well (#18777), the orange dot is the T2 observation well at 4 m (#19450), the yellow dot targets the T1 aquifer well (#19179), the white dots are T2 piezometers at 50 m, and green dots are observation wells at 75 m, 120 m and 300 m (from Barry *et al.*, 2009)

Source of recycled water, intended uses, receiving environments & routes of exposure

Source of recycled water: sewage – Salisbury & Adelaide trunk mains

Current use: *commercial food crop* irrigation in Northern Adelaide Plains

- Current treatment & supply: via Bolivar WWTP & RWTP & VPS

Future use: *commercial food crop* irrigation

- NAIS processes & storage options in development

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Endpoints & routes of exposure to recycled water

Current human endpoint

1. *Crop consumption*
2. *Accidental ingestion:* of recycled water (as aerosol inhalation) due to irrigation via sprinklers:
   - *By growers/irrigators*
   - *By local communities*

- *Accidental consumption:* due to cross-connection of pipelines

Endpoints & routes of exposure to recycled water

Environmental endpoints

1. *Irrigated crops via sprinklers/spray*

- Crops currently grown in VPS area include): Broad acre, Glasshouse & Perennial (from Marks & Boon, 2005)

2. *Soil beneath the irrigated crops*

- Five soil types in the NAP: ranging from loamy sands to medium clay (from Stevens *et al*., 2003)

3. *Storage - aquifer receiving the recycled water*

- Ensuring the protection of the *beneficial uses* & *environmental values* of the aquifer is paramount.

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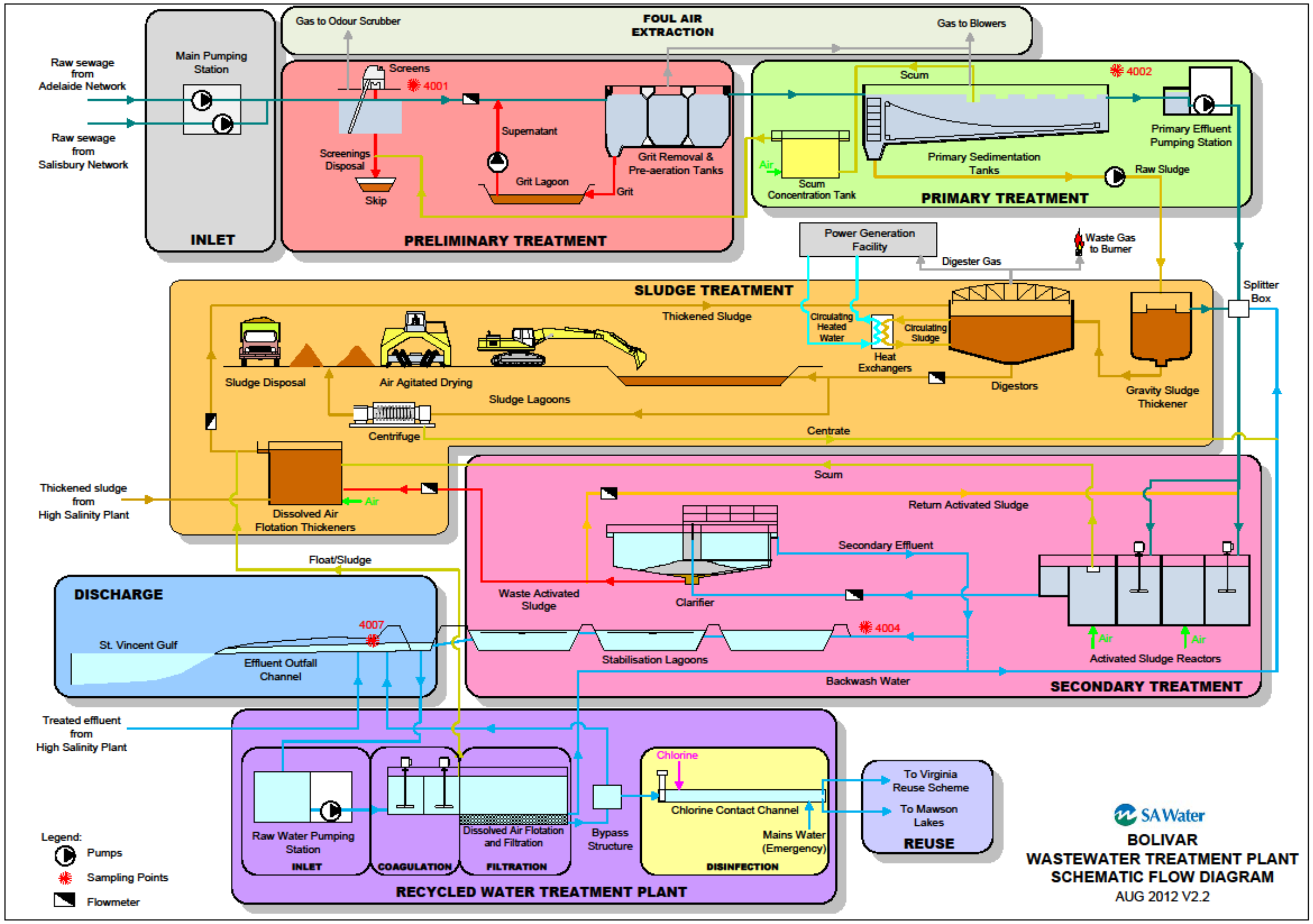
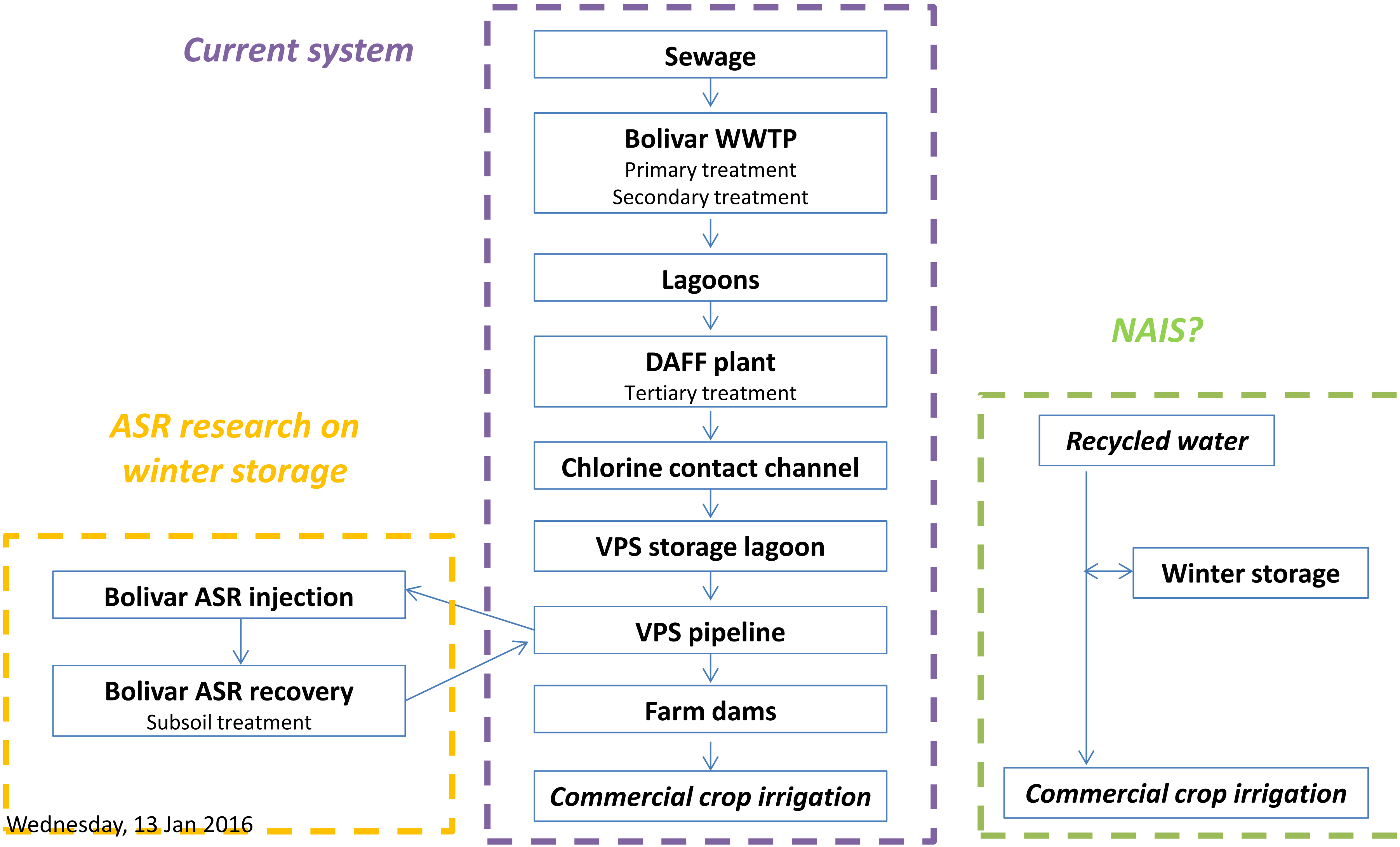
Bolivar recycled water process



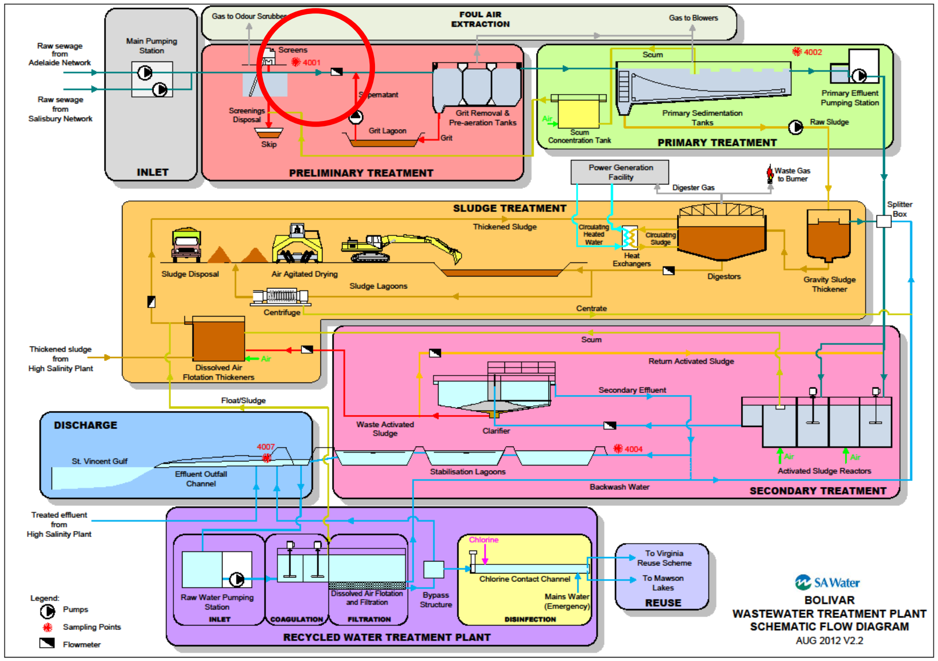
Recycled water system components



Available information to inform risk assessment

- Water quality data from routine program
- Process performance
- Research investigations
- Previous incidents & effectiveness of corrective responses

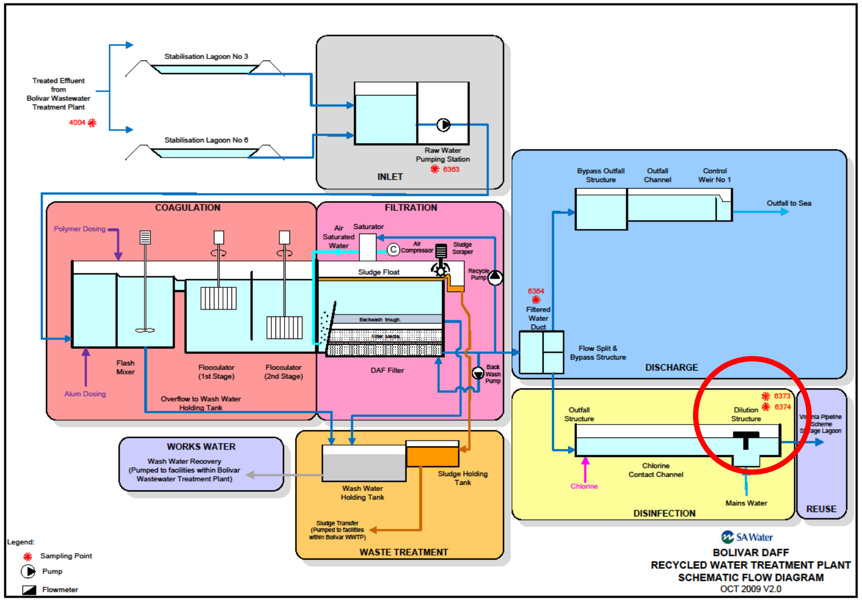
Current Bolivar water quality sampling points



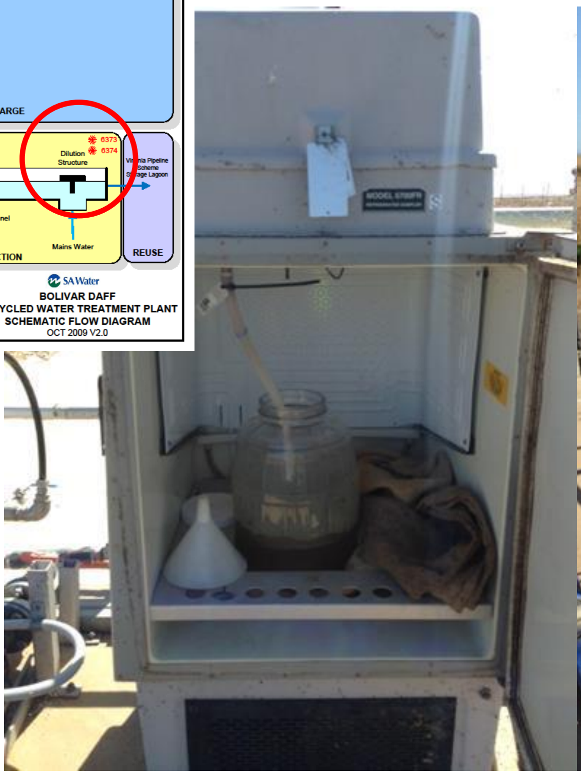
Sewage

SP4001 (composite sampler) for chemical

Current Bolivar water quality sampling points



Recycled water
SP6373 (grab tap) for microbiological
SP6374 (composite sampler) for chemical



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Current Bolivar routine water quality sampling program

Table 20 Summary of routine verification monitoring activities

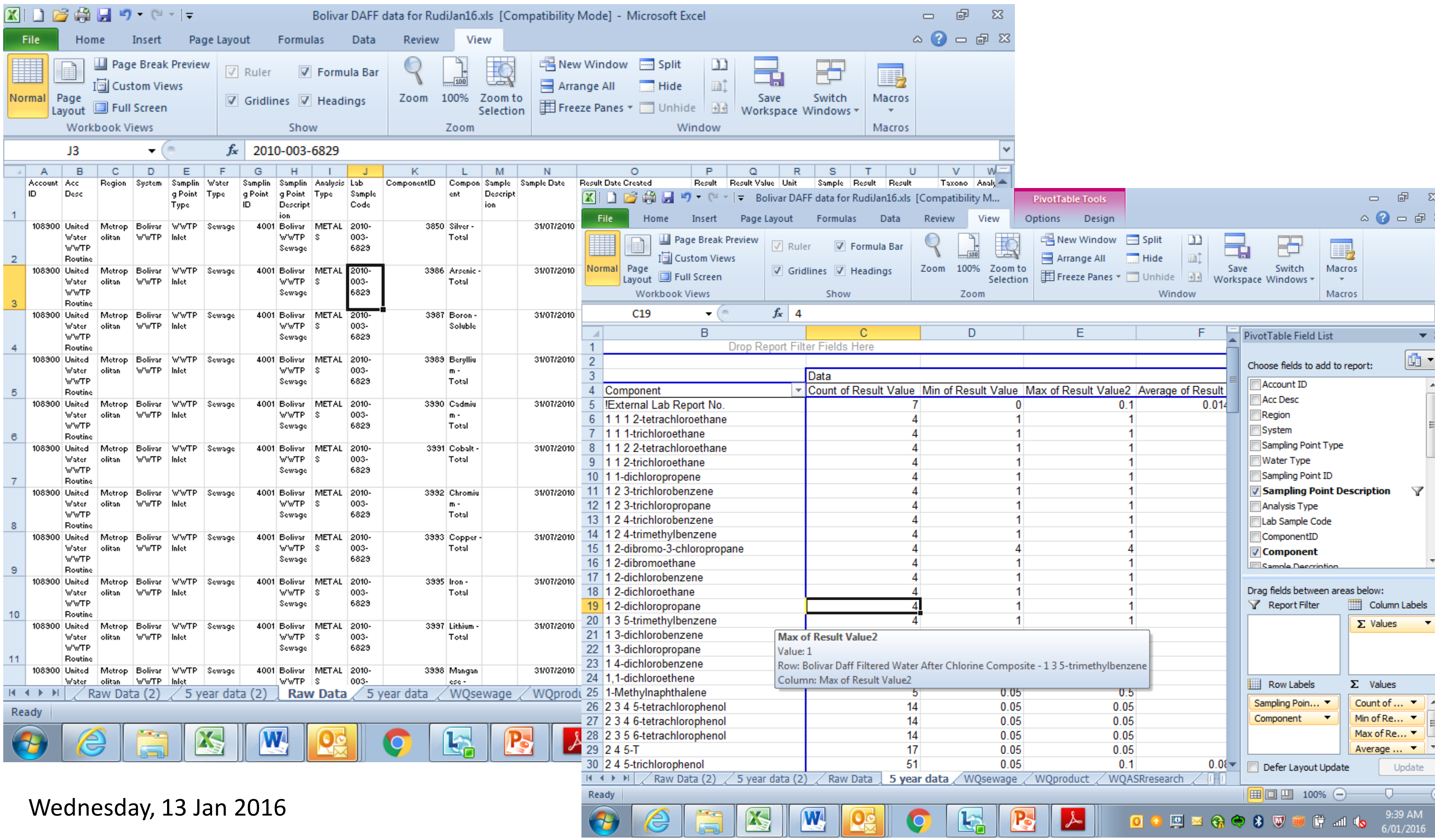
Location	Parameters	Frequency
Lagoon influent (SP4004)	Nitrogen - Ammonia	Daily
	Biochemical Oxygen Demand Suspended Solids pH Nitrogen - TKN, Oxidised Phosphorus	6-daily
	Chemical Oxygen Demand Alkalinity	12-daily
	Protozoa	7-daily (Dec-Mar) 14-daily (Apr-Nov)
Lagoon effluent (SP4007)	Biochemical Oxygen Demand$_{(total \& soluble)}$ pH Conductivity Total Dissolved Solids Dissolved Oxygen Nitrogen – Ammonia, TKN, Oxidised	6-daily
	E. coli	Weekly
	Phosphorus Alkalinity	12-daily
	Chemical Oxygen Demand Suspended Solids Temperature Colour Turbidity Cations - Ca, Mg, K, Na Sulphate Metals - Al, Sb, Ar, Be, B, Cd, Cr, Co, Cu, Fe, Pb, Li, Mn, Hg, Mo, Ni, Se, Ag, Th, Sn, Va, Zn	24-daily
	Chloride	28-daily
	Herbicides, Pesticides, Volatile Organic Compounds, Halogenated Phenols, Poly Aromatic Hydrocarbons, Cyanide, PCBs	Yearly
DAFF raw water (SP6363)	Algal Count	7-daily
DAFF recycled product water (SP6374)	*E. coli* Chlorine Algal Count	7-daily
DAFF recycled product water (SP6373)	Biochemical Oxygen Demand (Total) Nitrogen- TKN, Oxidised Nitrogen	6-daily
	pH Phosphorus Cations - Ca, Mg, K, Na Anions - Cl^-, F^- Alkalinity Sodium Adsorption Ratio Metals - Al, Sb, Ar, Be, Ba, B, Cd, Cr$_{(total \& VI)}$, Co, Cu, Fe, Pb, Li, Mn, Hg, Mo, Ni, Se, Ag, Th, Sn, Va, Zn	28-daily
	Herbicides, Pesticides, Volatile Organic Compounds, Halogenated Phenols, Poly Aromatic Hydrocarbons, Cyanide, PCBs	Yearly

APPENDIX A

Monitoring of Chemical Quality of Product Water from the DAFF Plant

Parameter	Frequency of Testing	Criteria
soluble BOD_5	Weekly	20 mg/L
Arsenic	Monthly	0.1 mg/L
Barium	Monthly	1.0 mg/L
Beryllium	Monthly	0.1 mg/L
Boron	Monthly	4.0 mg/L
Cadmium	Monthly	0.01 mg/L
Chromium	Monthly	1.0 mg/L
Chromium VI	Monthly	0.1 mg/L
Cobalt	Monthly	0.05 mg/L
Lead	Monthly	0.2 mg/L
Manganese	Monthly	2.0 mg/L
Mercury	Monthly	0.002 mg/L
Molybdenum	Monthly	0.05 mg/L
Nickel	Monthly	0.2 mg/L
Selenium	Monthly	0.01 mg/L
Total Cyanide	Yearly	0.05 mg/L
Polychlorinated Biphenyls	Yearly	0.5 µg/L
Total Herbicides *atrazine* *simazine*	3 Monthly	Limit of quantification 0.5 µg/L 0.5 µg/L
Total Insecticides *endosulfan* *chlorpyrifos*	Yearly	Limit of quantification 0.5 µg/L 0.5 µg/L

Today: raw data & 5 year statistical analysis (2010-15)



Hazard identification

- Risk assessment considers the approach outlined in the AGWR (2006)
- Need to compare water quality to the relevant public health and environmental guideline.
- Need to determine **Maximal risk** = risk if untreated sewage was supplied to growers directly or in the case of a MAR scheme, was injected into an aquifer & also supplied to growers
- Need to determine **Residual risk** assessment = risk which includes the preventive measures/ multiple barriers of the system: WWTP (primary & secondary treatment), lagoons, RWTP (media filtration, chlorine disinfection).

*for chemical parameters, compare *mean value* to the guideline for each of the different endpoints

- Need to also consider the likelihood & consequence of the risk & hazardous events.

Potential hazards in sewage

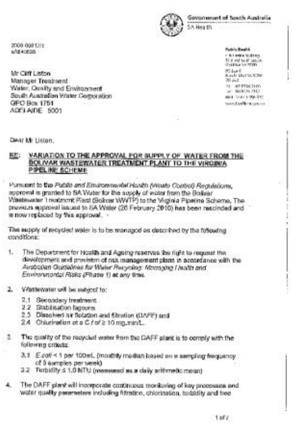
Table 2.2 Potential hazards found in sewage

Classification	Examples of constituents
Conventional	• Suspended solids • Biochemical oxygen demand • Total organic carbon • Ammonia, nitrate, nitrite, total nitrogen • Phosphorus • Metals • Surfactants • Organic chemicals • Pesticides • Total dissolved solids/salinity • Bacteria • Helminths • Protozoa • Viruses
Emerging	• Prescription and non-prescription drugs — antipyretic, antibiotics, antacids, anti-inflammatory, etc • Home care products • Veterinary and human antibiotics • Industrial and household products • Sex and steroidal hormones • Other endocrine disrupters (hormonally active agents) • Water disinfection byproducts — N-nitrosodimethylamine (NDMA)

Source: Adapted from Tchobanoglous et al (2003)

PART B
CONSOLIDATION OF PUBLIC HEALTH ASPECTS

Key guidelines – to assess water quality & public health



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SA Health

Mr Cliff Liston
Manager Treatment
Water, Quality and Environment
South Australian Water Corporation
GPO Box 1751
ADELAIDE 5001

Dear Mr Liston,

RE: VARIATION TO THE APPROVAL FOR SUPPLY OF WATER FROM THE BOLIVAR WASTEWATER TREATMENT PLANT TO THE VIRGINIA PIPELINE SCHEME

Pursuant to the *Public and Environmental Health (Waste Control) Regulations*, approval is granted to SA Water for the supply of water from the Bolivar Wastewater Treatment Plant (Bolivar WWTP) to the Virginia Pipeline Scheme. The previous approval issued to SA Water (26 February 2010) has been rescinded and is now replaced by this approval.

The supply of recycled water is to be managed as described by the following conditions:

1. The Department for Health and Ageing reserves the right to request the development and provision of risk management plans in accordance with the *Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1)* at any time.
2. Wastewater will be subject to:
   - 2.1 Secondary treatment
   - 2.2 Stabilisation lagoons
   - 2.3 Dissolved air flotation and filtration (DAFF) and
   - 2.4 Chlorination at a C.t of ≥ 10 mg.min/L.
3. The quality of the recycled water from the DAFF plant is to comply with the following criteria:
   - 3.1 *E.coli* < 1 per 100mL (monthly median based on a sampling frequency of 3 samples per week)
   - 3.2 Turbidity ≤ 1.0 NTU (measured as a daily arithmetic mean)
4. The DAFF plant will incorporate continuous monitoring of key processes and water quality parameters including filtration, chlorination, turbidity and free

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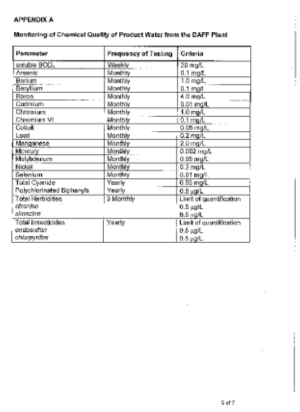

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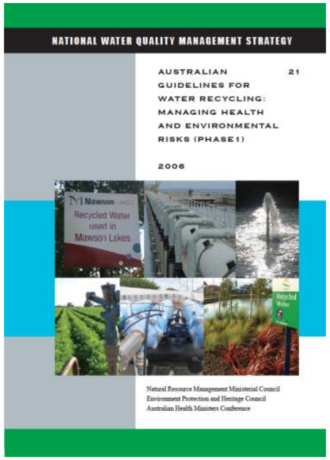
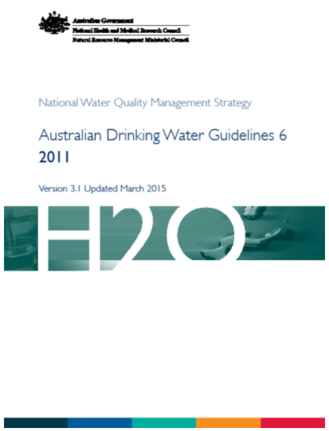
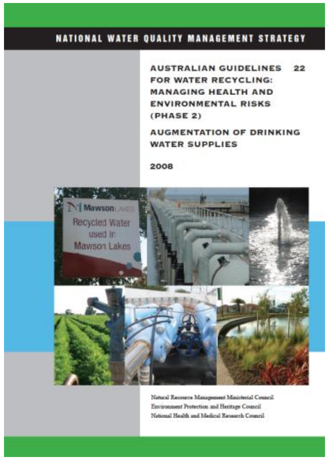
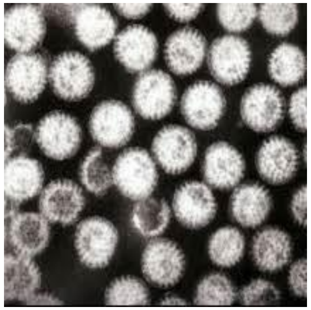






Pathogens: *Commercial food crops* & health based targets



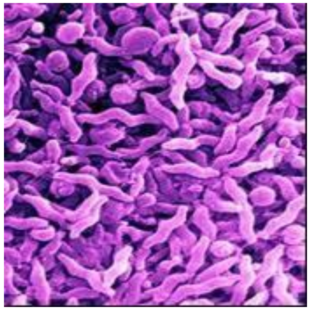


Table 3.8 (continued)

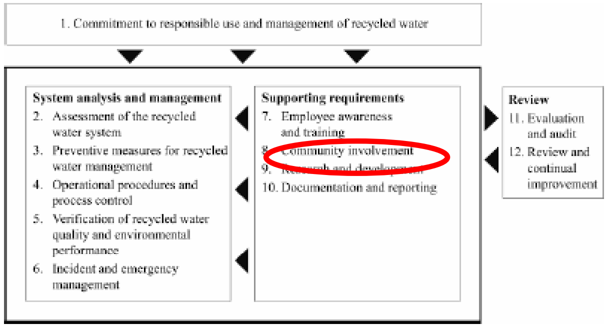
Log reduction targets (V, P, B)[a]	Indicative treatment process	Log reductions achievable by treatment (V, P, B)	On-site preventive measures	Exposure reduction[b]	Water quality objectives[c]
Landscape irrigation — trees, shrubs, public gardens, etc					
5.0 3.5 4.0	Secondary treatment or primary treatment with lagoon detention	0.5–2.0 0.5–2.0 1.0–3.0	Combinations of: • microspray • drip irrigation • no public access	 2.0 4.0 3.0	• BOD <20 mg/L[d] • SS <30 mg/ L[d] • *E. coli* <1000 cfu/100 mL (if not disinfected)
Commercial food crops consumed raw or unprocessed					
6.0 5.0 5.0	Advanced treatment to achieve total pathogen removal required (eg secondary, filtration and disinfection)	6.0 5.0 5.0	• None required, although pathogen reduction will occur between harvesting and sale • The recycled water can be used for all crop applications, including spray irrigation of salad crops	0.5 V, B	• To be determined on case-by-case basis, depending on technologies • Could include turbidity criteria for filtration, disinfectant Ct or dose (UV) • *E. coli* <1 per 100 mL
Commercial food crops					
6.0 5.0 5.0	Secondary treatment with >25 days lagoon detention and disinfection	3.0–4.0 2.0–4.0 >6.0	Consumers • Crops with limited or no ground contact and eaten raw (eg tomatoes, capsicums) — drip irrigation and no harvest of wet or dropped produce • Crops with ground contact with skins removed before consumption (eg watermelons) — if spray irrigation, minimum 2 days between final irrigation and harvest • Pathogen reduction between harvesting and sale *Public in vicinity of irrigation area*[f] • No access and drip or subsurface irrigation • No access during irrigation and if spray irrigation, minimum 25–30 m buffer	 3.0 3.0–4.0 0.5/ day V, B 6.0 4.0	• BOD <20 mg/L[d] • SS <30 mg/ L[d] • Disinfectant residual (eg minimum chlorine residual) or UV dose[e] • *E. coli* <100 cfu/100 mL

e Aim is to demonstrate reliability of disinfection and ability to consistently achieve microbial quality
f Log reductions for public in the vicinity of commercial food crop irrigation areas should comply with total log reductions required for municipal use.

Wednesday, 13 Jan 2016

Pathogens: Bolivar – validation research on removal

- Adelaide metro WWTP (Bolivar, Glenelg, Christies): protozoa & virus removal (Keegan, 2009)
- Bolivar WWTP: protozoa & virus removal (Keegan & Wati, 2012)
- Bolivar stabilisation lagoons: virus & protozoa removal (Keegan, 2010)
- Bolivar DAFF reuse plant: challenge testing with Bakers yeast for protozoa, MS-2 for viruses (Keegan, 2009)
- Chlorination/ chloramination (*C.t*): virus inactivation @ different pH, turbidity (Keegan *et al.*, 2012)
- Protozoa: *Cryptosporidium* infectivity (King *et al.*, 2015)



Pathogens: Bolivar health based targets

Barrier/ process	Virus	Protozoa	Bacteria
Primary & secondary treatment	2.0	1.0	1.0
Lagoons	1.5	2.0	2.0
DAFF: coagulation/filtration	0.5	2.0	1.0
Chlorine disinfection	2.0	0.0	2.0
Total	**6.0**	**5.0**	**6.0**
Consumers of produce	6.0	5.0	5.0
Public in the vicinity	5.0	3.5	4.0

1 log = 90%
2 log = 99%
3 log = 99.9%
4 log = 99.99%
5 log = 99.999%
6 log = 99.9999%

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Bolivar-VPS DHA supply approval (e.g. filter performance)

7. The target turbidity of the product water from the DAFF plant in the filtered water duct should be less than 0.5 NTU and the product water turbidity must be less than 1 NTU measured as a daily arithmetic mean. If the turbidity exceeds 5 NTU for more than 60 minutes the product water is to be diverted and not supplied to the Virginia Pipeline Scheme until the turbidity is reduced below 5 NTU.

8. Turbidity of the product water will be monitored continuously in the filtered water duct. Turbidity of effluent produced by all individual filters will be monitored continually with the interval between turbidity measurements on any single filter unit not exceeding 45 minutes when the filter is in operation. Monitoring results will be available as direct readouts and will be recorded and stored.

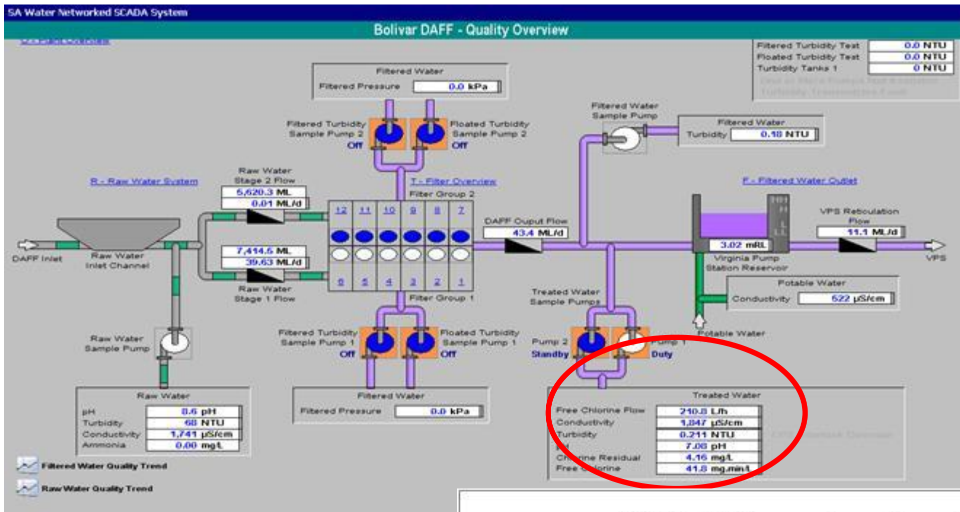
Bolivar recycled water scheme operating plan

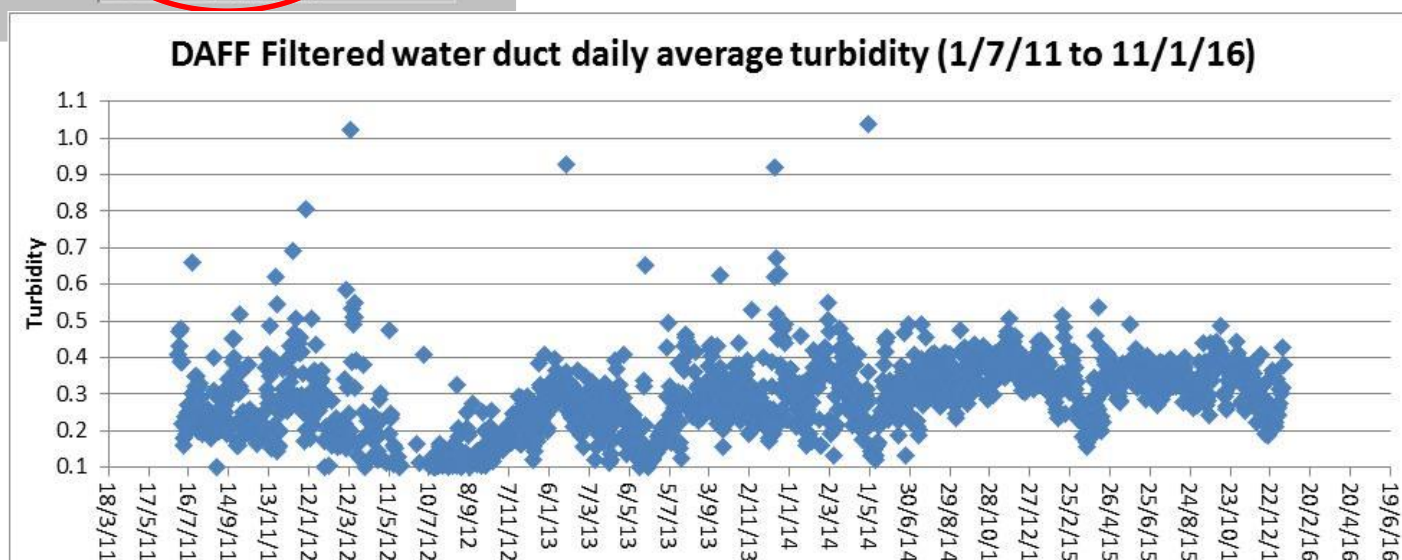
SA Water | Allwater
Adelaide Services Alliance

Allwater Do. No.: TMD-5026-OP-0088
Title: Bolivar Recycled Water Water Quality Operating Plan
Document Type: RWQMS - WQOP

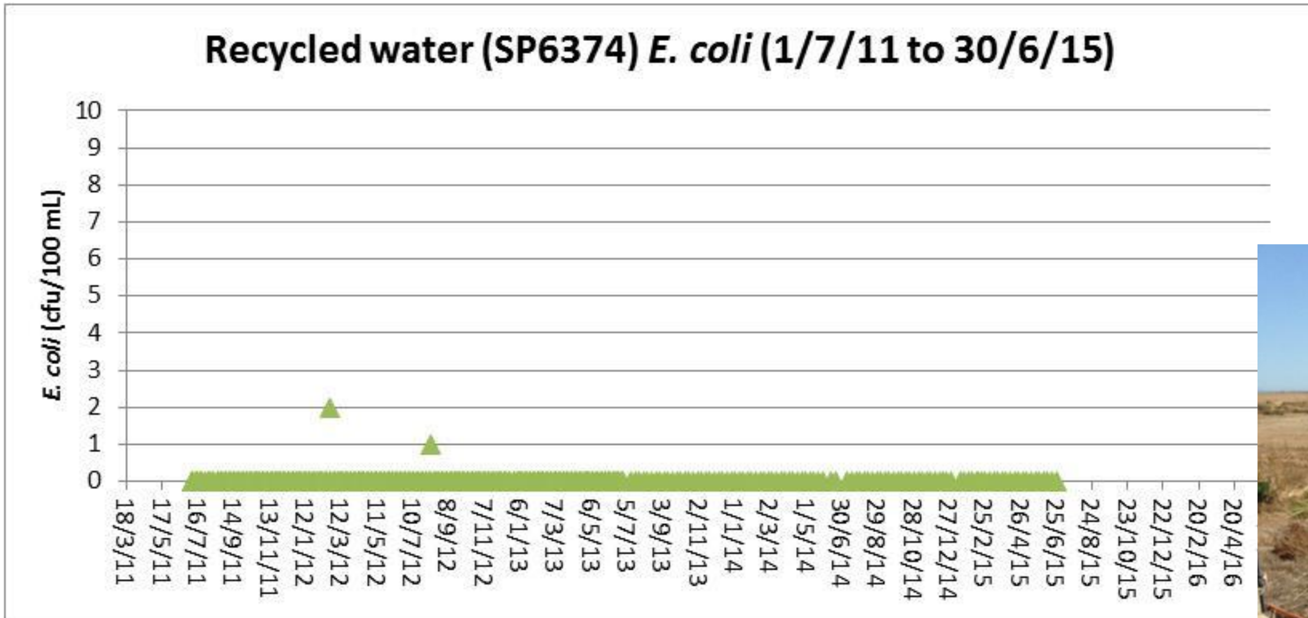
Area	Critical Control Point*	Measurement of Critical Control Point	Parameter	Sample Point Location	Health Limit / SPI/IM (Critical limit)	Guideline System Operational Target	Indicative value at meter for system target	SCADA alarm set-point				Bypass trigger		Shutdown trigger		Incident Notification Category	Operational Response to Operational target deviation/CCP critical limit deviation
								LoLo	Lo	Hi	HiHi	LoLo	HiHi	LoLo	HiHi		
		Effluent ammonia	Ammonia	Lagoon influent (Daily composite sample SP4004)	SPI: Annual median ≤ 1.0 mg/L; 95% of sample ≤ 2 mg/L	0.2-1 mg/L										SPI at risk When lagoon influent ammonia is > 1 mg/L under normal operational condition.	• Check aeration system/MLSS • Measure DO at outlet of each basin • Measure DO profile of problem basin • Advise supervisor of outcome and increase DO set points if necessary • Change swing zone back to aeration if necessary
		Effluent SS	SS	Lagoon influent (Daily composite sample SP4004)	SPI: Annual median ≤ 30 mg/L	<30 mg/L										SPI at risk When lagoon influent SS is > 30 mg/L under normal operational condition.	• Check if carry over occurs at SSTs during high flow • Check RAS pump operation normal • Check and adjust SST distribution valve position if necessary • Advise supervisor and adjust wasting if MLSS too high • Advise supervisor if wasting is limited by sludge process
	Stabilisation lagoons	Total area of online lagoons	Lagoon area	Stabilisation lagoon		> 220 ha										Type 2 Incident When lagoon areas < 220 ha.	• Ensure at least Lagoon 1,2,3 are online
St Kilda DAFF RWTP	Flocculation /coagulation	Floc formation visual inspection	Floc size	Mixing chambers and flocculation bays													• Investigate & rectify any chemical dosing faults • Investigate & rectify any flocculator faults • Undertake jar test & adjust chemical dosing if necessary.
	Floatation	Individual floated turbidity	Turbidity	Individual online floated turbidity meter		< 5 NTU											• Investigate & rectify any chemical dosing faults • Investigate & rectify any flocculator faults • Undertake jar test & adjust chemical dosing if necessary.
	Filtration	Individual filtered turbidity	Filtered turbidity	Individual filtered turbidity meter	SPI: 95% of time in each month must ≤ 0.5 NTU	< 0.5 NTU										SPI at risk When individual filter turbidity is > 0.5 NTU.	• Flushing turbidity meter if sample flow is low • Review floated turbidity, if > 10 NTU, check and rectify blockage in poly dosing line if necessary • Review filter DP, initiate filter backwash, reduce filter run time set point if necessary.
		Combined filtrate turbidity	Turbidity	Online FWD turbidity meter	Daily average turbidity > 1NTU or Online turbidity > 5 NTU continuously for > 60 min and production is not stopped. SPI: Daily average ≤0.5 NTU for 95.0% of days of a contract year	0.3-0.5 NTU				0.5 NTU (15 min)	0.5 NTU (30 min)		0.5 NTU (30 min)		SCADA: 4.5 NTU (immediately) CPS: 10 NTU (immediately)	WQ Type 1 incident When daily average turbidity > 1NTU or Online turbidity > 5 NTU continuously for > 60 min and production is not stopped. WQ Type 2 incident When production stopped due to high filtered water tubditiy (other than a Type 1 incident) SPI at risk When FWD turbidityis > 0.5 NTU.	• Manually operate plant on bypass on SCADA alarm (Hi) • Investigate if alarm is genuine by flushing turbidity meter and grab sample test, if not, bring plant back online • If alarm is genuine, investigate if it is FWD level related. If yes, increase plant flow to increase FWD level; • If filter performance issue, investigate coagulation/flocculation, undertake jar test and adjust chemical dosing, or backwash individual filters if necessary. Reduce filter run time set point if necessary. • If raw water turbidity is > 100NTU not resulting from an algal bloom, notify supervisor and activate Contingency plan (TMP-5026-OP-0077 ERP D-13 Contingency plans for Bolivar DAFF plant) • Plant will auto shutdown on SCADA Alarm Hihi shutdown trigger: manually start plant on bypass mode, carry out above response • Plant will shut down on CPS alarm hihi shutdown trigger if SCADA shutdown failed: Grab sample to confirm high turbidity. Notify Incident Manager immediately to initiate IM process. Put CPS on bypass, and manually start plant on bypass mode, carry out above response procedure. • Initiate TMP-5026-OP-0077 ERP D-13 Contingency plans for Bolivar DAFF plant if incident occurs
	pH	Product water pH	pH	Online meter end of Contact Channel	6-8.5 (SPI: [illegible] any day of a Contract Year, pH must be between 6 and 8.5.)	6-8.5		6.1	6.5	8	8.4					[illegible] When product pH is < 6 or >8.5 under normal operational condition.	• Verify online analyser reading by grab sample test, initiate calibration of meter if necessary • If pH deviation is low advise supervisor and adjust chemical dosing if possible without compromising treated water turbidity
	TDS	Product water TDS	TDS	Online meter at end of Contact Channel	< 1500 mg/L (SPI: 99.0% of any day of a Contract Year, TDS must be < 1500 mg/L.)	< 1200 mg/L				1200 mg/L (60 min)	1450 mg/L (15 min)					SPI at risk When product TDS is >1500 mg/L under normal operational condition.	• Product water TDS trend should be monitored and trending up above 1200 mg/L should be noted and advise supervisor • Automatic dilution should occur on SCADA alarm (hi) (this currently does not work) • Notify supervisor and reinstate dilution if triggered.

DAFF filter performance - turbidity





Bolivar recycled water - *E. coli* (verification)



DHA approval monthly median <1 /100 mL A/C
Type 1 incident: >10/100 mL A/C
Type 2 incident: >4/100 mL A/C

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Chemicals: *Commercial food crops* & Public health

Refer to AGWR (2006) section 3.5.4

Analyses of treated recycled water and associated water recycling schemes indicate that chemical quality generally complies with drinking water quality requirements for most parameters, including heavy metals, organic chemicals, pesticides and disinfection byproducts (NRC 1996, NRC 1998, USEPA 2004). This is confirmed by unpublished Australian data, which show the following:

- Average concentrations of nutrients, metals and trihalomethanes (THMs — produced as byproducts of disinfection) in filtered and chlorinated water from the Virginia Pipeline Scheme in South Australia essentially conform with ADWG values. Concentrations of pesticides, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), general organics and non-THM disinfection byproducts were largely below levels of detection. Nitrogen occasionally exceeded ADWG values, but nitrogen is a nutrient for which there is a recommended upper limit but no guideline value.

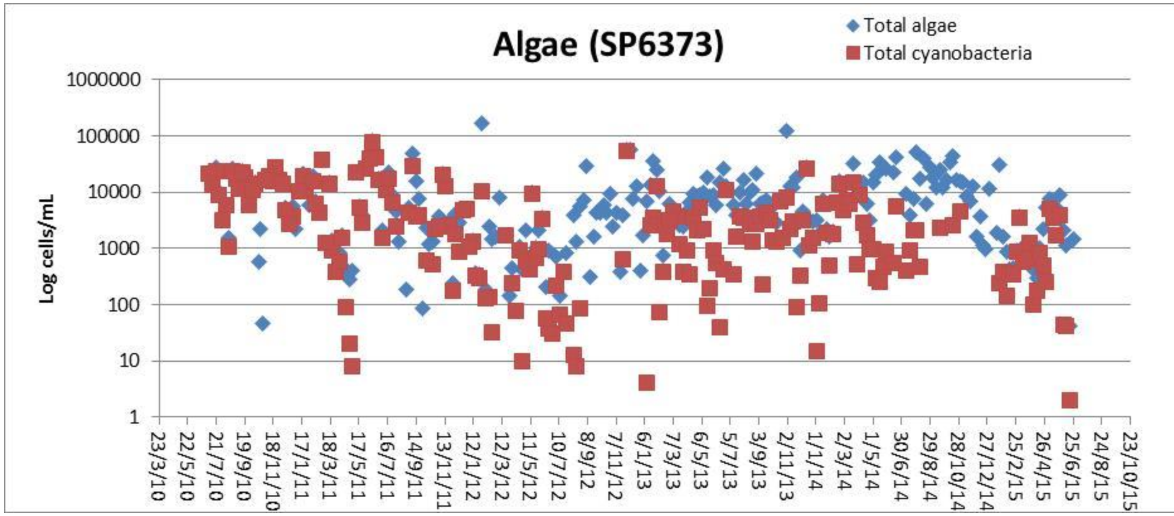
Go to excel spreadsheet

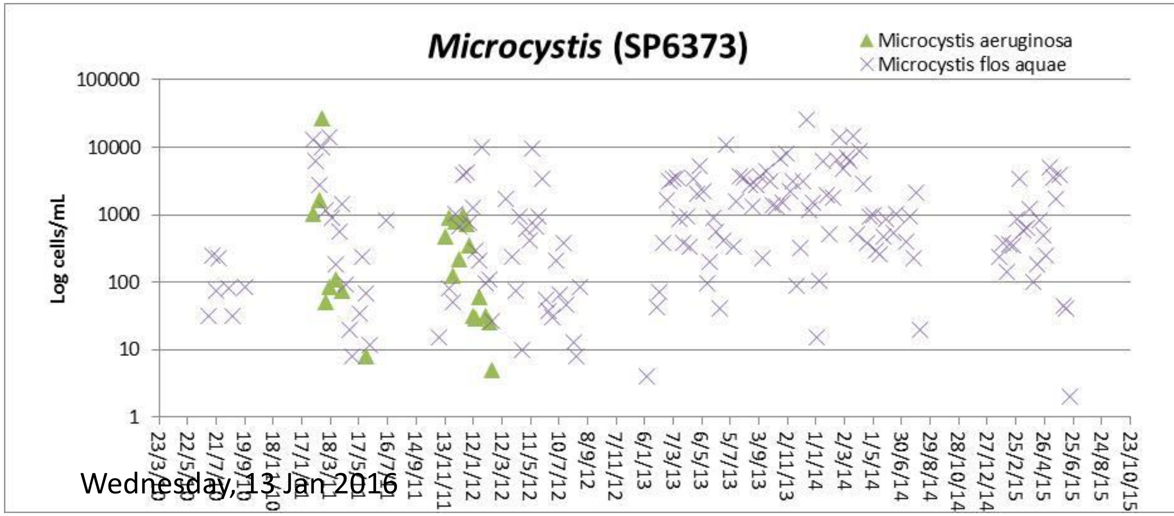
Parameter	Unit	LOR	n	min	max	mean	period	source	ADWG	LTV irri	STV irr	DHA	GW ref	GW ref
									T10.5	ANZECC	ANZECC	Bolivar	CSIRO	Gawler
Physical characteristics														
Conductivity	uS/cm	0.001	231	1540	2960	**2062**	2010-2015	SAW routine		650	650		3700	
Dissolved oxygen	mg/L	0.1					2010-2015	SAW routine					0.3	
pH		0.1	245	6.7	7.5	7.2	2010-2015	SAW routine	6.5-8.5a	6-8.5	6-8.5		7	
Suspended solids	mg/L	0.1	260	34	860	**405**	2010-2015	SAW routine					5	
Total dissolved solids	mg/L	1	231	850	1600	**1136**	2010-2015	SAW routine	600a				2009	
Major ions and SAR														
Alkalinity as CaCO3														
Potassium	mg/L		1	28.6	28.6	28.6	2010-2015	SAW routine						
Sulphate	mg/L		24	95.4	534.0	132.9	2010-2015	SAW routine	250a					
Microbiological														
Cryptosporidium								SAW routine						
Giardia								SAW routine						
Nutrients								SAW routine						
Ammonia	mg/L	0.005	244	27.6	57.3	**44.2**	2010-2015	SAW routine	0.5a	5	25-125		0.06	
BOD	mg/L	2	182	134	740	**326**	2010-2015	SAW routine				20		
COD	mg/L	50	203	255	1590	**803**	2010-2015	SAW routine						
Phosphorous - total	mg/L	0.005	117	1	29	**11**	2010-2015	SAW routine		0.05	0.8-12		0.024	
TKN	mg/L	0.05	286	46	111	**72**	2010-2015	SAW routine					0.064	
TN	mg/L		126	50	111	**72**	2010-2015	SAW routine						
Nitrate	mg/L							SAW routine	50					
Nitrite	mg/L							SAW routine	3					
Metals, metalloids, halogens														
Aluminium total	mg/L	0.005	59	0.5	17.6	**7.2**	2010-2015	SAW routine	0.2	5.0	20.0		0.0	
Antimony total	mg/L	0.0005	60	0.0005	0.0022	**0.0007**	2010-2015	SAW routine	0.003					
Arsenic total	mg/L		60	0.0008	0.0042	**0.0022**	2010-2015	SAW routine	0.01	0.1	2	0.1	0.0047	
Barium total	mg/L	0.0005					2010-2015	SAW routine	2			1		
Beryllium soluble	mg/L	0.0005					2010-2015	SAW routine	0.06			0.1		
Beryllium total	mg/L	0.0005	60	0.0003	0.0003	**0.0003**	2010-2015	SAW routine	0.06	0.1	0.5	0.1		
Boron soluble	mg/L	0.04	60	0.16	1.39	**0.35**	2010-2015	SAW routine	4	0.5	0.5	4	0.11	
Cadmium total	mg/L	0.0002	60	0.00010	0.00100	**0.00034**	2010-2015	SAW routine	0.002	0.01	0.05	0.01	<0.0002	
Chromium total	mg/L	0.003	60	0.002	0.082	**0.008**	2010-2015	SAW routine	0.05			1	<0.03[5]	
Cobalt total	mg/L	0.0005	60	0.0005	0.0016	**0.0011**	2010-2015	SAW routine		0.05	0.1	0.05		
Copper total	mg/L	0.001	60	0.04	0.21	**0.11**	2010-2015	SAW routine	1 to 2	0.2	5		<0.03[5]	
Iron total	mg/L	0.03	60	0.6	3.0	**1.5**	2010-2015	SAW routine	0.3a	0.2	10		1.3	
Lead total	mg/L	0.0005	60	0.0064	0.0378	**0.0154**	2010-2015	SAW routine	0.01	2	5	0.2	<0.001	
Lithium total	mg/L	0.001	60	0.0057	0.0429	**0.0087**	2010-2015	SAW routine		2.5	2.5		<0.01	
Manganese total	mg/L	0.0005	60	0.08	0.19	**0.11**	2010-2015	SAW routine	).1 to 0.5	0.2	10	2	0.05	
Mercury total	mg/L	0.0005	60	0.0000	0.0013	**0.0002**	2010-2015	SAW routine	0.001	0.002	0.002	0.002	<0.0003	
Molybdeum total	mg/L	0.0005	60	0.0023	0.0144	**0.0057**	2010-2015	SAW routine	0.05	0.01	0.05	0.05		
Nickel total	mg/L	0.0005	60	0.0045	0.0198	**0.0086**	2010-2015	SAW routine	0.02	0.2	2	0.2	0.0011	
Selenium total	mg/L	0.003	60	0.0001	0.0096	**0.0035**	2010-2015	SAW routine	0.01	0.02	0.05	0.01		
Silver total	mg/L	0.0002	60	0.0001	0.0032	**0.0009**	2010-2015	SAW routine	0.1					
Thallium total	mg/L	0.0005	60	0.0001	0.0004	0.0001	2010-2015	SAW routine						
Tin total	mg/L	0.0005	60	0.0028	0.0096	0.0061	2010-2015	SAW routine						
Vandadium total	mg/L	0.003	48	0.0001	0.0191	**0.0064**	2010-2015	SAW routine		0.1	0.5			
Zinc total	mg/L	0.003	60	0.10	0.24	**0.15**	2010-2015	SAW routine	3a	2	5		0.042	
Organic compounds														
Phenols	mg/L	0.01	58	0.01	0.23	0.08	2010-2015	SAW routine						
Other							2010-2015							
Cyanide total	mg/L	0.05	58	0.05	0.05	0.05	2010-2015	SAW routine						
Grease	mg/L	1	57	32	159	74	2010-2015	SAW routine						
MEB			34	2.2	7.9	4.8	2010-2015	SAW routine						

Emerging chemicals

- E.g. Endocrine disrupting chemicals (Holmes *et al*., 2010)
  - Sampled non-estrogen indicator EDCs (nonyl phenol mono- & di-ethoxylates, 4-t-octylphenol, 4-nonyl phenol, bisphenol (plasticizer) & estrogens (17 β-estradiol, estrone, 17-α-ethynylestradiol)
  - Bioassay (yeast screen assay)
  - Estradiol equivalence (EEq) conc provides an indication of overall estrogenic potency, Bolivar WWT reduces EEq by 97%
- E.g. Disinfection by-products
  - Chlorine from disinfection reacts with organic matter to produce DBPs such as trihalomethanes (THMs) & haloacetic acids (HAAs)
  - Bolivar ASR measured in injectant, reduction in aquifer & none in recovery, not a concern for irrigation (Barry *et al*., 2010)

Algae & cyanobacteria





Phytoplankton recorded in recycled water

Species	Phylum	Order	Family
Cyclotella	Bacillariophyceae	Centrales	Coscinodiscaceae
Cyclotella small_spp	Bacillariophyceae	Centrales	Coscinodiscaceae
Navicula	Bacillariophyceae	Pennales	Naviculaceae
Nitzschia	Bacillariophyceae	Pennales	Nitzschiaceae
Actinastrum	Chlorophyta	Chlorococcales	Scenedesmaceae
Ankistrodesmus	Chlorophyta	Chlorococcales	Oocystaceae
Ankistrodesmus sp 2 (small cells)	Chlorophyta	Chlorococcales	Oocystaceae
Ankyra	Chlorophyta	Chlorococcales	Chlorococcaeceae
Botryococcus	Chlorophyta	Chlorococcales	Dictyosphaerium
Chlorella	Chlorophyta	Chlorococcales	Oocystaceae
Coelastrum	Chlorophyta	Chlorococcales	Scenedesmaceae
Crudgenia	Chlorophyta	Chlorococcales	Scenedesmaceae
Dictyosphaerium	Chlorophyta	Chlorococcales	Dictyosphaerium
Dictyosphaerium sp_2_(small_cells)	Chlorophyta	Chlorococcales	Dictyosphaerium
Dimorphococcus	Chlorophyta	Chlorococcales	Dictyosphaeriaceae
Elakatothrix	Chlorophyta	Chlorococcales	Coccomyxaceae
Kirchneriella	Chlorophyta	Chlorococcales	Oocystaceae
Oocystis	Chlorophyta	Chlorococcales	Oocystaceae
Oocystis sp 2 (large cells)	Chlorophyta	Chlorococcales	Oocystaceae
Oocystis sp_1_(small_cells)	Chlorophyta	Chlorococcales	Oocystaceae
Pediastrum	Chlorophyta	Chlorococcales	Scenedesmaceae
Scenedesmus	Chlorophyta	Chlorococcales	Scenedesmaceae
Sphaerocystis	Chlorophyta	Chlorococcales	Palmellaceae
Tetrastrum	Chlorophyta	Chlorococcales	Scenedesmaceae
Asterococcus	Chlorophyta	Tetrasporales	Asterococcus
Stichococcus	Chlorophyta	Ulotrichales	Ulotrichaceae
Ulothrix	Chlorophyta	Ulotrichales	Ulotrichaceae
Chlamydomonas	Chlorophyta	Volvocales	chlamydomonadaceae
Closterium	Chlorophyta	Zygnematales	Desmidiaceae
Mallomonas	Chrysophyta	Ochromomales	Synuraceae
Cryptomonas	Cryptophyta		Cryptomonadaceae
Aphanocapsa	Cyanophyta	Chroococcales	Chroococcaceae
Microcystis aeruginosa	Cyanophyta	Chroococcales	Chroococcaceae
Microcystis flos-aquae	Cyanophyta	Chroococcales	Chroococcaceae
Synechocystis	Cyanophyta	Chroococcales	Chroococcaceae
Phormidium broad_spp	Cyanophyta	Oscillatoriales	Oscillatoriaceae
Planktothrix	Cyanophyta	Oscillatoriales	Phormidiaceae
Euglena	Euglenophyta	Euglenales	Euglenaceae
Chroomonas	Cryptophyta	Cryptomonales	Cryptomonadaceae
Cyanodictyon	Cyanophyta	Chroococcales	Synechococcaceae
Didymocystis	Chlorophyta	Chlorococcales	Scenedesmaceae
Geitlerinema	Cyanophyta	Oscillatoriales	Phormidiaceae
Monoraphidium	Chlorophyta	Chlorococcales	Oocystaceae
Monoraphidium sp_2_(short)	Chlorophyta	Chlorococcales	Oocystaceae
Planctonema	Chlorophyta	Ulotrichales	Ulotrichaceae
Pseudodidymocystis	Chlorophyta	Chlorococcales	Scenedesmaceae
Staurosira	Chrysophyta	Pennales	Fragilariaceae

Outcome - public health hazards

Hazard	Sewage Maximal risk		Recycled water Residual risk	
	Crop consumption	Accidental aerosol inhalation	Crop consumption	Accidental aerosol inhalation
Pathogens			HBT met for 6, 5 , 5, *E. coli*	
Inorganic chemicals		Al> DW Fe> Aesth Pb> DW Mn> Aesth	Cl> Aesth Na> Aesth	
Salinity & sodicity		TDS> Aesth		TDS> Aesth
Nutrients		NH_4> Aesth		
Organic chemicals				
Turbidity & particulates				

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PART C
ENVIRONMENTAL ASPECTS

Key issues in relation to irrigation water quality

Table 4.2.1 Key issues concerning irrigation water quality effects on soil, plants and water resources

	Key Issues
Soil	Root zone salinity
	Soil structural stability
	Build-up of contaminants in soil
	Release of contaminants from soil to crops & pastures
Plants	Yield
	Salt tolerance
	Specific ion tolerance
	Foliar injury
	Uptake of toxicants in produce for human consumption
	Contamination by pathogens
Water resources	Deep drainage & leaching below root zone
	Movement of salts, nutrients & contaminants to groundwaters & surface waters
Important associated factors	Quantity and seasonality of rainfall
	Soil properties
	Crop and pasture species and management options
	Land type
	Groundwater depth and quality

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Recycled water – key hazards for agriculture (crops & soil)

Table 4.2 Key environmental hazards, environmental endpoints and common effects on the environment when using recycled water for agricultural, municipal, residential and fire-control purposes

Hazard	Environmental endpoint	Effect or impact on the environment
Boron	Accumulation in soil	Plant toxicity
Cadmium	A low risk with respect to cadmium concentrations in recycled water, but cadmium already in soils can be made more readily available to plants if chloride concentrations increase. Chloride can be measured indirectly, but reliably, as salinity (see the salinity section below).	
Chlorine disinfection residuals	Plants	Direct toxicity to plants
	Surface waters	Toxicity to aquatic biota
Hydraulic loading (water)	Soil	Waterlogging of plants
	Groundwaters	Waterlogging of plants
	Groundwaters	Soil salinity (secondary)
Nitrogen	Soils	Nutrient imbalance in plants
	Soils	Pest and disease in plants
	Soils	Eutrophication of soils and effects on terrestrial biota
	Surface waters	Eutrophication
	Groundwaters	Contamination
Phosphorus	Soils	Eutrophication of soils and toxic effects on phosphorus sensitive terrestrial biota (native plants)
	Surface waters	Eutrophication
Salinity	Infrastructure	Salinity may cause rising damp or corrosion of assets; this can also arise from excessive hydraulic load (secondary salinity)
	Soils	Plants stressed from osmotic affects of soil salinity
	Soils	Contamination of soils by increasing plant availability of cadmium that is already in the soil
	Surface water	Increasing the salinity of fresh groundwaters
	Groundwater	Increasing the salinity of fresh surface waters
Chloride	Plants	Direct toxicity to plants when sprayed on leaves
	Soils	Plant toxicity via uptake through the root
	Surface water	Toxicity to aquatic biota
Sodium	Plants	Direct toxicity to plants when sprayed on leaves
	Soils	Plant toxicity via uptake through the root
	Soils	Soil structure decline due to sodicity

\+
others as outlined in ANZECC & ARMCANZ (2000) for irrigation

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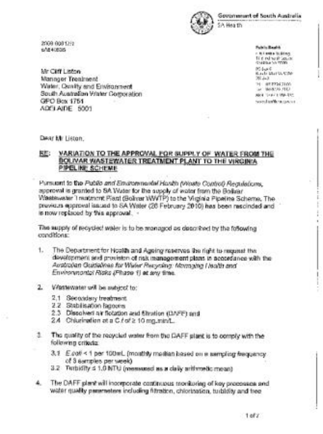
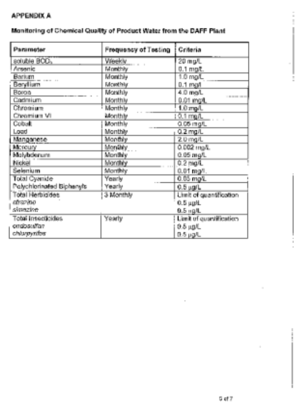
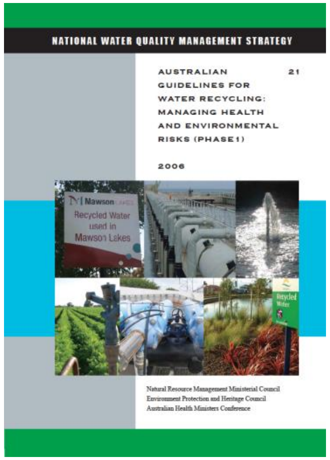
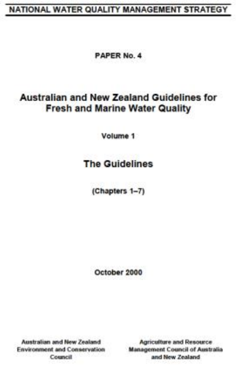
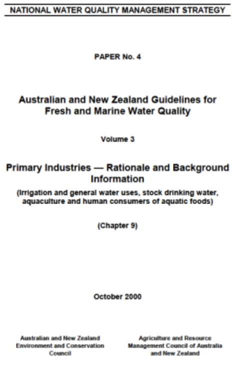
Key guidelines – to assess water quality for environment (crops, soil)











ANZECC & ARMCANZ (2000) :
Chapter 4: Primary industries
Chapter 9: Irrigation & general use

LTV = Long term value, max conc of contaminant which can be tolerated for 100 years
STV = short term value, max conc of contaminant which can be tolerated for 20 years

Bolivar sewage

Parameter	Unit	LOR	n	min	max	mean	period	source	ADWG	LTV irri	STV irr	DHA	GW ref	GW ref
									T10.5	ANZECC	ANZECC	Bolivar	CSIRO	Gawler
Physical characteristics														
Conductivity	uS/cm	0.001	231	1540	2960	2062	2010-2015	SAW routine		650	650		3700	
Dissolved oxygen	mg/L	0.1					2010-2015	SAW routine					0.3	
pH		0.1	245	6.7	7.5	7.2	2010-2015	SAW routine	6.5-8.5a	6-8.5	6-8.5		7	
Suspended solids	mg/L	0.1	260	34	860	405	2010-2015	SAW routine					5	
Total dissolved solids	mg/L	1	231	850	1600	1136	2010-2015	SAW routine	600a				2009	
Major ions and SAR														
Alkalinity as CaCO3														
Potassium	mg/L		1	28.6	28.6	28.6	2010-2015	SAW routine						
Sulphate	mg/L		24	95.4	534.0	132.9	2010-2015	SAW routine	250a					
Microbiological														
Cryptosporidium								SAW routine						
Giardia								SAW routine						
Nutrients								SAW routine						
Ammonia	mg/L	0.005	244	27.6	57.3	44.2	2010-2015	SAW routine	0.5a	5	25-125		0.06	
BOD	mg/L	2	182	134	740	326	2010-2015	SAW routine				20		
COD	mg/L	50	203	255	1590	803	2010-2015	SAW routine						
Phosphorous - total	mg/L	0.005	117	1	29	11	2010-2015	SAW routine		0.05	0.8-12		0.024	
TKN	mg/L	0.05	286	46	111	72	2010-2015	SAW routine					0.064	
TN	mg/L		126	50	111	72	2010-2015	SAW routine						
Nitrate	mg/L							SAW routine	50					
Nitrite	mg/L							SAW routine	3					
Metals, metalloids, halogens														
Aluminium total	mg/L	0.005	59	0.5	17.6	7.2	2010-2015	SAW routine	0.2	5.0	20.0		0.0	
Antimony total	mg/L	0.0005	60	0.0005	0.0022	0.0007	2010-2015	SAW routine	0.003					
Arsenic total	mg/L		60	0.0008	0.0042	0.0022	2010-2015	SAW routine	0.01	0.1	2	0.1	0.0047	
Barium total	mg/L	0.0005					2010-2015	SAW routine	2			1		
Beryllium soluble	mg/L	0.0005					2010-2015	SAW routine	0.06			0.1		
Beryllium total	mg/L	0.0005	60	0.0003	0.0003	0.0003	2010-2015	SAW routine	0.06	0.1	0.5	0.1		
Boron soluble	mg/L	0.04	60	0.16	1.39	0.35	2010-2015	SAW routine	4	0.5	0.5	4	0.11	
Cadmium total	mg/L	0.0002	60	0.00010	0.00100	0.00034	2010-2015	SAW routine	0.002	0.01	0.05	0.01	<0.0002	
Chromium total	mg/L	0.003	60	0.002	0.082	0.008	2010-2015	SAW routine	0.05			1	<0.03[5]	
Cobalt total	mg/L	0.0005	60	0.0005	0.0016	0.0011	2010-2015	SAW routine		0.05	0.1	0.05		
Copper total	mg/L	0.001	60	0.04	0.21	0.11	2010-2015	SAW routine	1 to 2	0.2	5		<0.03[5]	
Iron total	mg/L	0.03	60	0.6	3.0	1.5	2010-2015	SAW routine	0.3a	0.2	10		1.3	
Lead total	mg/L	0.0005	60	0.0064	0.0378	0.0154	2010-2015	SAW routine	0.01	2	5	0.2	<0.001	
Lithium total	mg/L	0.001	60	0.0057	0.0429	0.0087	2010-2015	SAW routine		2.5	2.5		<0.01	
Manganese total	mg/L	0.0005	60	0.08	0.19	0.11	2010-2015	SAW routine	0.1 to 0.5	0.2	10	2	0.05	
Mercury total	mg/L	0.0005	60	0.0000	0.0013	0.0002	2010-2015	SAW routine	0.001	0.002	0.002	0.002	<0.0003	
Molybdeum total	mg/L	0.0005	60	0.0023	0.0144	0.0057	2010-2015	SAW routine	0.05	0.01	0.05	0.05		
Nickel total	mg/L	0.0005	60	0.0045	0.0198	0.0086	2010-2015	SAW routine	0.02	0.2	2	0.2	0.0011	
Selenium total	mg/L	0.003	60	0.0001	0.0096	0.0035	2010-2015	SAW routine	0.01	0.02	0.05	0.01		
Silver total	mg/L	0.0002	60	0.0001	0.0032	0.0009	2010-2015	SAW routine	0.1					
Thallium total	mg/L	0.0005	60	0.0001	0.0004	0.0001	2010-2015	SAW routine						
Tin total	mg/L	0.0005	60	0.0028	0.0096	0.0061	2010-2015	SAW routine						
Vandadium total	mg/L	0.003	48	0.0001	0.0191	0.0064	2010-2015	SAW routine		0.1	0.5			
Zinc total	mg/L	0.003	60	0.10	0.24	0.15	2010-2015	SAW routine	3a	2	5		0.042	
Organic compounds														
Phenols	mg/L	0.01	58	0.01	0.23	0.08	2010-2015	SAW routine						
Other							2010-2015							
Cyanide total	mg/L	0.05	58	0.05	0.05	0.05	2010-2015	SAW routine						
Grease	mg/L	1	57	32	159	74	2010-2015	SAW routine						
MEB			34	2.2	7.9	4.8	2010-2015	SAW routine						

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A check on boron

Recycled water mean value = 0.33 mg/L

A5.3 Boron

Table A5.3 Maximum boron concentrations in irrigation or soil water tolerated by a variety of crops, without reduction in yields

Species name	Common name
Very sensitive (threshold 0.3–0.5 mg/L)	
Citrus limon	Lemon
Rubus sp	Blackberry
Sensitive (threshold 0.5–0.75 mg/L)	
Persea americana	Avocado
C. x paradisi	Grapefruit
C. sinensis	Orange
Prunus armeniaca	Apricot
P. persica	Peach
P. avium	Cherry
P. domestica	Plum
Diospyros kaki	Persimmon
Ficus carica	Fig, kadota
Vitis vinifera	Grape
Juglans regia	Walnut
Carya illinoinenis	Pecan
Allium cepa	Onion
A. sativum	Garlic
Ipomea batatas	Sweet potato
Triticum aestivum	Wheat
Helianthus annuus	Sunflower
Vigna radiata	Bean, mung
Sesamum indicum	Sesame
Lupinus hartwegii	Lupine
Fragaria sp.	Strawberry
Helianthus tuberosus	Artichoke, Jerusalem
Phaseolus vulgaris	Bean, kidney
P. vulgaris	Bean, snap
P. lunatus	Bean, lima
Arachis hypogaea	Peanut
Moderately sensitive (threshold 1.0–2.0 mg/L)	
Brassica oleracea botrytis	Broccoli
Capsicum annuum	Pepper, red
Pisum sativa	Pea
Daucus carota	Carrot
Raphanus sativus	Radish
Solanum tuberosum	Potato
Cucumis stivus	Cucumber
Lactuca sativa	Lettuce
Moderately tolerant (threshold 2.0–4.0 mg/L)	
Brassica oleracea capitata	Cabbage
B. rapa	Turnip
Poa pratensis	Bluegrass, Kentucky
Hordeum vulgare	Barley
Vigna unguiculata	Cowpea
Avena sativa	Oats
Zea mays	Corn
Cynara scolymus	Artichoke
Nicotiana tabacum	Tobacco
Brassica juncea	Mustard
Melilotus indica	Clover, sweet
Cucurbita pepo	Squash

Table A5.3 (continued)

Species name	Common name
Cucumis melo	Muskmelon
B. oleracea botrytis	Cauliflower
Tolerant (threshold 4.0–6.0 mg/L)	
Medicago sativa	Alfalfa
Vicia benghalensis	Vetch, purple
Petroselinum crispum	Parsley
Beta vulgaris	Beet, red
B. vulgaris	Sugar beet
Lycopersicum	Tomato
Very tolerant (threshold 6.0–15.0 mg/L)	
Sorghum bicolor	Sorghum
Gossypium hirsutum	Cotton
Apium graveolens	Celery
Asparagus officinalis	Asparagus

Note: Boron tolerance may vary, depending upon climate, soil conditions and crop variety.
Source: Maas (1986, 1990b); Keren and Bingham (1985).

A check on cadmium

Recycled water mean Cd = 0.0003 mg/L, Cl^- = 406 mg/L, TDS = 1,1,35 mg/L

A5.4 Cadmium

Table A5.5 Guidelines values for cadmium in recycled water

Limit	Value
Long-term trigger value in irrigation water	0.01 mg/L
Short-term trigger value in irrigation water (short-term use)	0.05 mg/L
Cumulative contaminant loading in soil receiving irrigation water	2 kg/ha

Table A5.6 Relationship between irrigation water chloride concentration or salinity, and risk of increasing crop uptake of cadmium

	Water quality parameter		
Chloride (mg/L)	Total dissolved solids (mg/L)	Electrical conductivity (dS/m)	Likelihood of increasing crop cadmium concentrations
<350	<1100	<1.9	Low
350–750	1100–1650	1.9–2.8	Moderate
>750	>1650	>2.8	High

Source: Modified from ANZECC and ARMCANZ (2000a); electrical conductivity and chloride data from Australian sewage treatment plants

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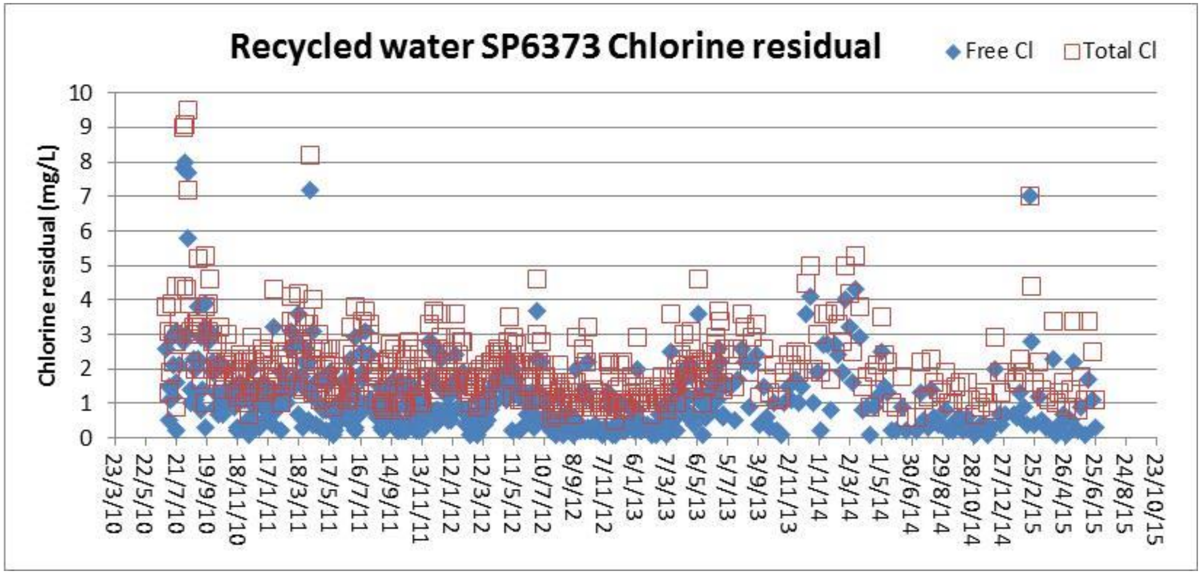
A check on chlorine residual



- Need chlorine for disinfection & unrestricted use
- Improved ammonia removal & greater control on chlorine dosing
- Online continuous monitoring & chlorine *C.t* calculation
- Storage lagoon/ distribution system, decreases residual
- AGWR (2006) – A4.2, target criteria 1-5 mg/L depending on plants

Salinity & sodicity

- Sewage TDS: 850-1,600 mg/L, EC: 1.5-2.9 dS/m
- Recycled water TDS: 850-1,310 mg/L
- Strong seasonality
- Irrigation salinity rating: Medium
- Key factors: soil characteristics, climate, plant species, irrigation management
- 5 soil types, most common is loamy sands ~>20% LF

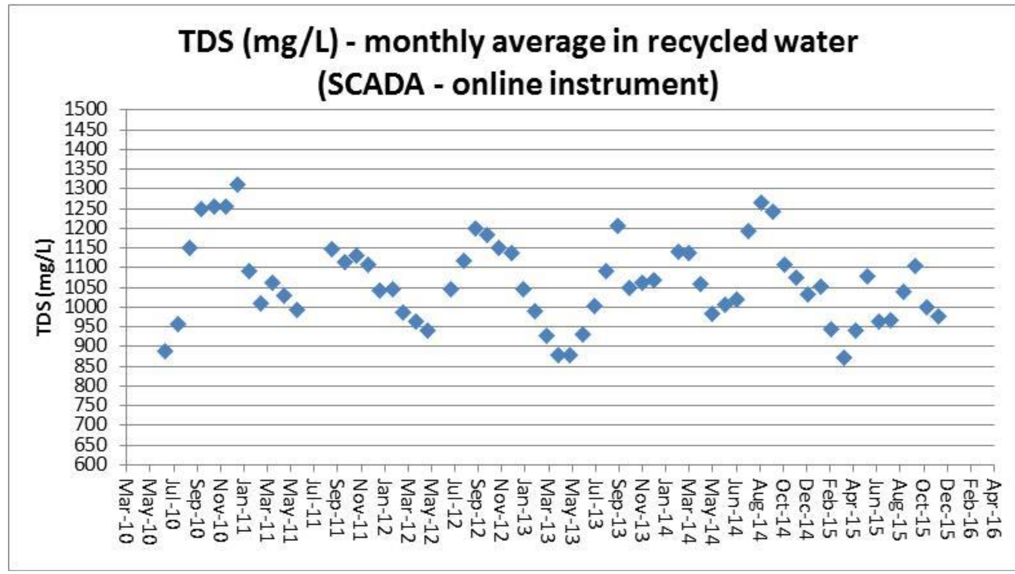


Table 9.2.5 Irrigation water salinity ratings based on electrical conductivity[a]

EC (dS/m)[b]	Water salinity rating	Plant suitability
<0.65	Very low	Sensitive crops
0.65–1.3	Low	Moderately sensitive crops
1.3–2.9	Medium	Moderately tolerant crops
2.9–5.2	High	Tolerant crops
5.2–8.1	Very high	Very tolerant crops
>8.1	Extreme	Generally too saline

a Adapted from DNR (1997); b 1dS/m = 1000 µS/cm

Salinity

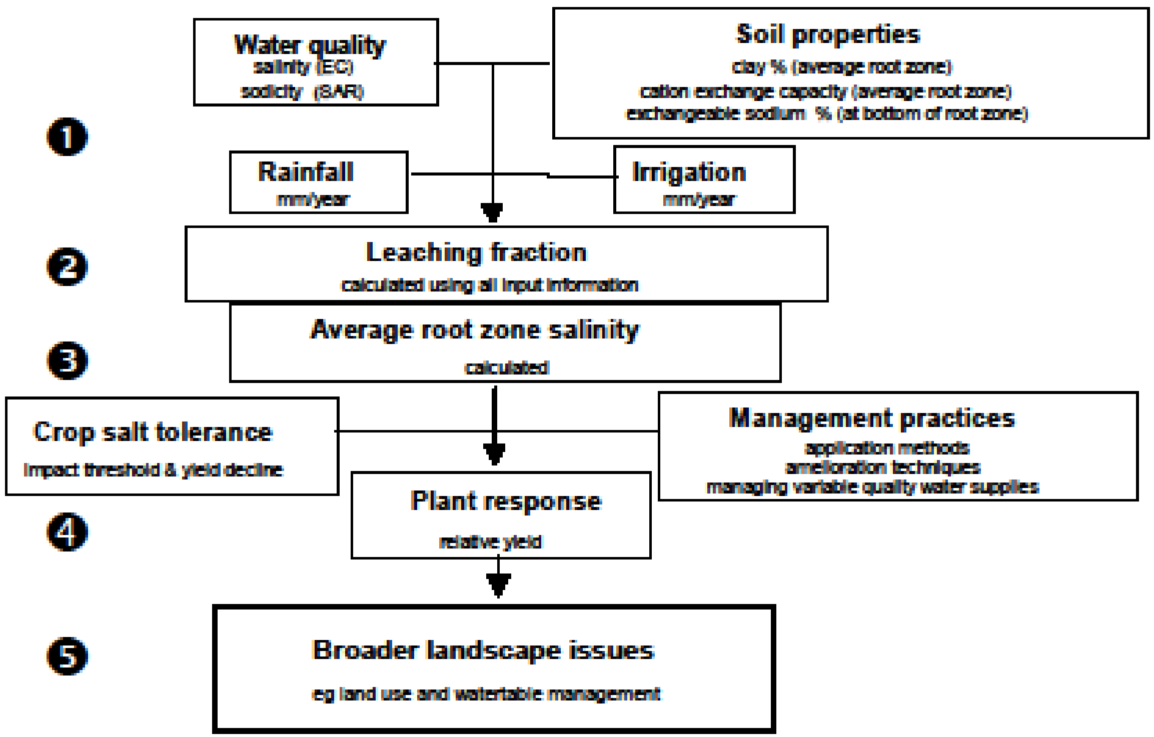


Figure 9.2.1 Flow diagram for evaluating salinity and sodicity impacts of irrigation water quality

Salinity (EC) & crop tolerance as a function of leaching fraction

Table A5.15 Approximate salinity tolerance of fruit, vegetable, grain and pasture crops

Scientific name	Common name	Salinity tolerance threshold (ECe dS/m)	Source	ECi[a]			
				25% LF (eg sand)	20% LF (eg sandy loam)	17% LF (eg loam)	12% LF (eg light clay)
Fruit crops							
Prunus dulcis	Almond	1.5–4	t, u	2.8	2.4	2.0	1.5
Malus sylvestris	Apple	1	t	1.0	0.9	0.7	0.6
Prunus armeniaca	Apricot	1.6	o	1.6	1.4	1.2	0.9
Persea americana	Avocado	1.3	t	1.3	1.1	1.0	0.7
Rubus spp	Blackberry, boysenberry, etc	1.5	o	1.5	1.3	1.1	0.8
Vitis spp	Grape	1.5–8	t, u, r	4.8	4.1	3.5	2.7
Citrus paradisi	Grapefruit	1.8–6	t, u	3.9	3.4	2.9	2.2
Citrus limonea	Lemon	1–6	t, u	3.5	3.0	2.6	2.0
Olea europaea	Olive	4	t	4.0	3.4	2.9	2.2
Citrus sinensis	Orange	1.7–6	t, u	3.9	3.3	2.8	2.2
Prunus persica	Peach	3.2	t	3.2	2.8	2.4	1.8
Pyrus spp	Pear	1	t	1.0	0.9	0.7	0.6
Cucurbita pepo pepo	Pumpkin	1.5–3*	o	2.3	1.9	1.7	1.3
Capsicum annuum	Pepper	1.5	o	1.5	1.3	1.1	0.8
Prunus domestica	Plum	1.5	o	1.5	1.3	1.1	0.8
Cucumis melo	Rockmelon	2.2	t	2.2	1.9	1.6	1.2
Fragaria spp	Strawberry	1	o	1.0	0.9	0.7	0.6
Lycopersicon esculentum	Tomato	2.3–2.5	t,o	2.4	2.1	1.8	1.3
Cucurbita pepo melopepo	Zucchini	4.7	o	4.7	4.1	3.5	2.6
Grain crops							
Hordeum vulgare	Barley	8	o	8.0	6.9	5.9	4.5
Brassica napus	Canola (oilseed rape)	2–4	r	3.0	2.6	2.2	1.7
Vicia faba	Faba bean	2–4	r	3.0	2.6	2.2	1.7
Lupinus angustifolium	Narrow-leaf lupin	2–4	r	3.0	2.6	2.2	1.7
Avena sativa	Oats	5	t	5.0	4.3	3.7	2.8
Zea mays	Corn, grain, sweet	1.7	t	1.7	1.5	1.3	1.0
Gossypium hirsutum	Cotton	7.7	t	7.7	6.6	5.7	4.3
Vigna unguiculata	Cowpea (seed)	1.6	t	1.6	1.4	1.2	0.9
Vigna unguiculata var Caloona	Cowpea, Caloona	2.0	t	2.0	1.7	1.5	1.1
Vinum usitatissimum	Flax/Linseed	1.7	t	1.7	1.5	1.3	1.0
Sorghum	Peanut	3.2	t	3.2	2.8	2.4	1.8
Sorghum, crooble	Phasey bean, Murray	0.8	t	0.8	0.7	0.6	0.4
Soybean	Rice, paddy	3	t	3.0	2.6	2.2	1.7
Carthamus tinctorius	Safflower	6.5	t	6.5	5.6	4.8	3.7
Sorghum bicolor	Sorghum	6.8	t	6.8	5.9	5.0	3.8

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Chloride & Sodium

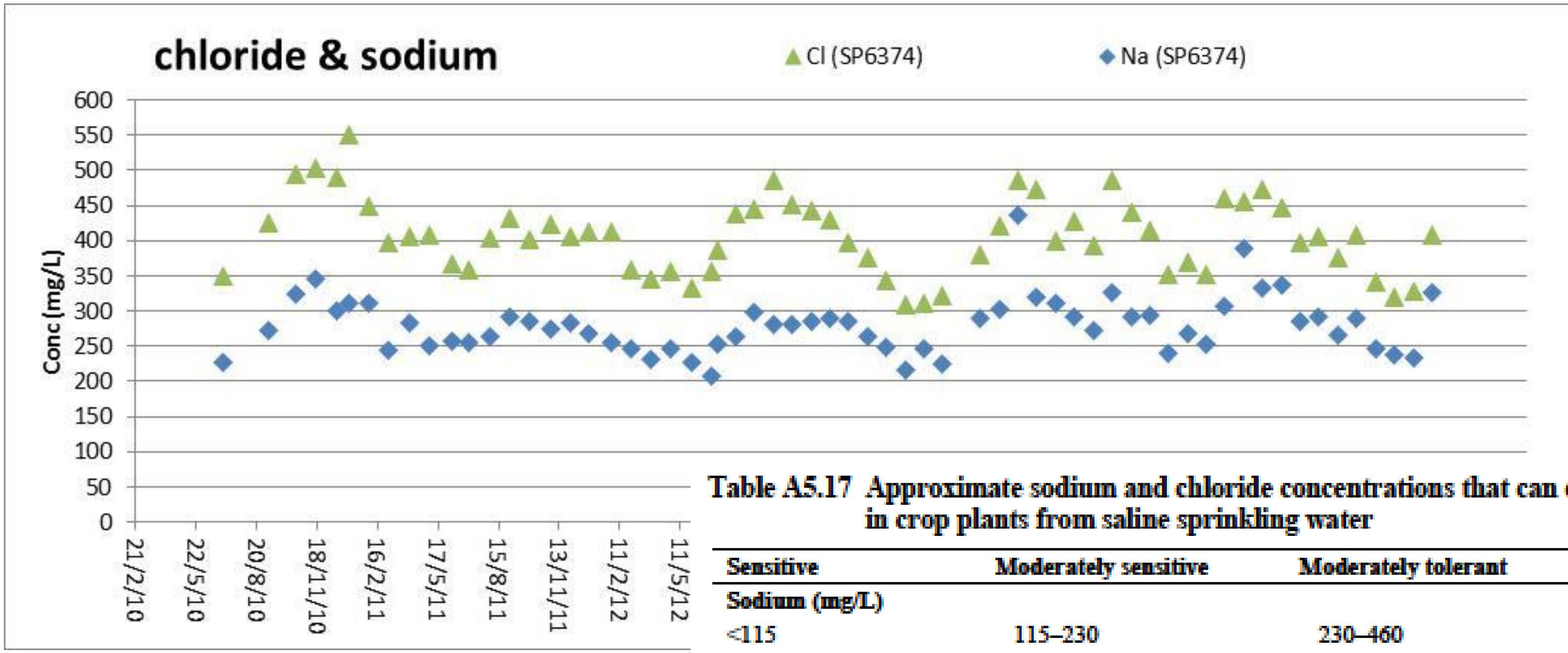


Table A5.17 Approximate sodium and chloride concentrations that can cause foliar injury in crop plants from saline sprinkling water

Sensitive	Moderately sensitive	Moderately tolerant	Tolerant
Sodium (mg/L)			
<115	115–230	230–460	>460
Chloride (mg/L)			
<175	175–350	350–700	>700
Almond	Pepper	Barley	Cauliflower
Apricot	Potato	Maize	Cotton
Citrus	Tomato	Cucumber	Sugar beet
Plum		Lucerne	Sunflower
Grape		Safflower	
		Sesame	
		Sorghum	

Note: Degree of injury is affected by site-specific environmental and agricultural conditions
Source: ANZECC and ARMCANZ (2000a) and Maas (1990a)

Sodium & soil structure (sodicicity)

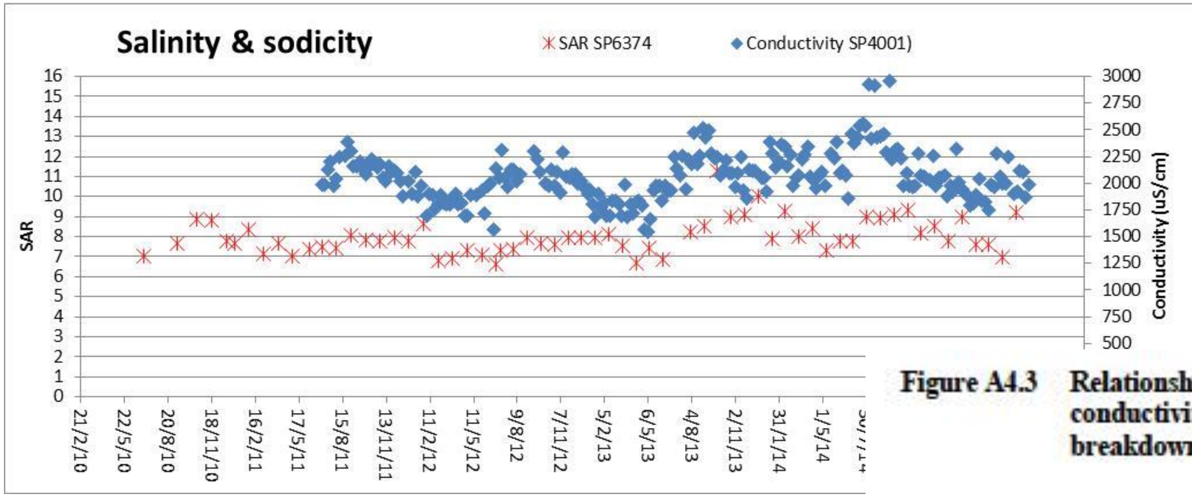
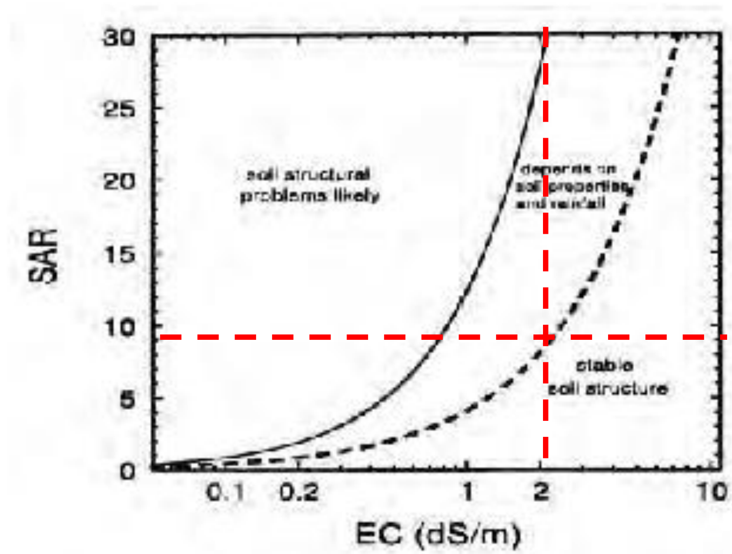


Figure A4.3 Relationship between sodium adsorption ratio (SAR) and electrical conductivity (EC) of irrigation water and likelihood of soil structure breakdown (source: ANZECC and ARMCANZ 2000a)



Sewage mean conductivity = 2,062 µS/cm = 2.0 dS/m, SAR = 8.0

Findings – environmental hazards

Hazard	Sewage Maximal risk		Recycled water Residual risk	
	Crops	Soils	Crops	Soils
Pathogens				
Inorganic chemicals		Al> LTV Fe> LTV		
Salinity & sodicity	TDS/ EC > LTV,STV		TDS/ EC > LTV,STV	
Nutrients	NH_3> LTV			
Organic chemicals				
Turbidity & particulates				

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Environmental residual risk with preventive measures

Recycled water supply

- Trade waste management in Bolivar catchment
- Bolivar WWTP (primary & secondary treatment)
- Bolivar WWTP lagoons
- Bolivar RWTP (DAFF process – coagulation, media filtration)
- Bolivar RWTP (chlorine disinfection)

+

Agricultural sector

- Soil properties
- Plant types
- Climate
- Landscape
- Irrigation management practices (e.g. leaching fraction, method, soil applicants)

PART D
MANAGED AQUIFER RECHARGE ASPECTS

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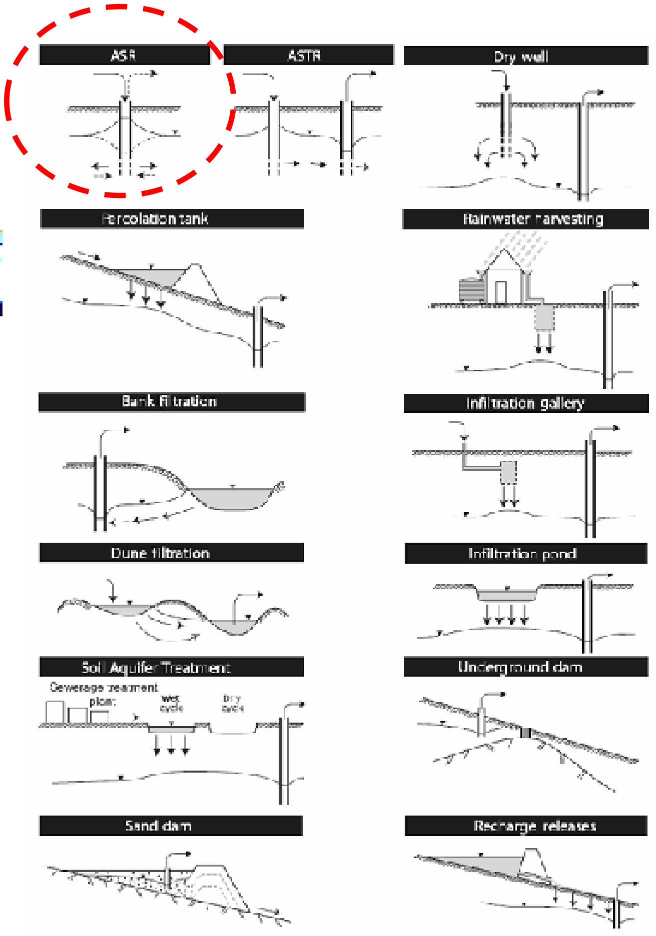
Background - what is MAR?

2.1 Definition, purposes and types of managed aquifer recharge

2.1.1 Definition and purposes of managed aquifer recharge

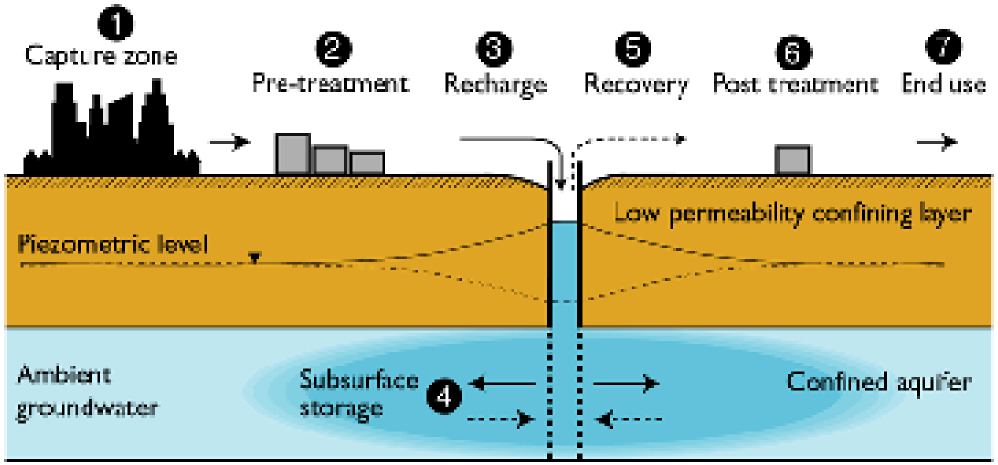
Managed aquifer recharge is the intentional recharge of water to aquifers for subsequen recovery or environmental benefit; the managed process assures adequate protection of human health and the environment. Aquifers may be recharged by diversion of water in wells or infiltration of water through the floor of basins, galleries or rivers.

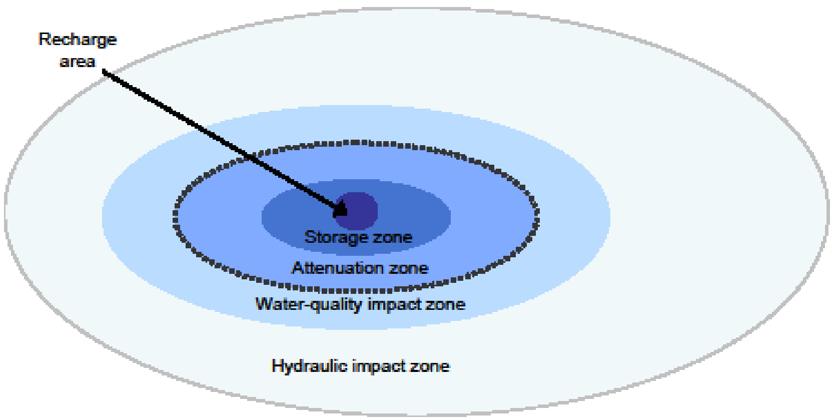


ASR = aquifer storage and recovery; ASTR = aquifer storage, transport and recovery.

Figure 2.2 **Schematic of types of managed aquifer recharge**

Generic components of an ASR scheme





The storage zone contains water that is fit for its intended use when recovered. Beyond the attenuation zone, the environmental values of the ambient groundwater are always preserved. Beyond the water-quality impact zone, there is no measurable change in groundwater quality. Beyond the hydraulic impact zone, there is no attributable change in hydraulic head (this zone is typically many times larger than the water-quality impact zone, especially for confined aquifers). The dotted line represents the maximum separation distance between the managed aquifer recharge structure and the observation well/s for verification monitoring, to ensure that the ambient groundwater is protected.

Figure 7.1 Schematic showing zones of influence of a managed aquifer recharge operation

Must consider aquifer environmental values – SA EPA

Environment Protection (Water Quality) Policy 2015—1.1.2016
Schedule 1—Environmental values of waters (clause 6)

Waters	Aquatic ecosystem	Recreation and aesthetics	Drinking water for human consumption	Primary industries—irrigation and general water uses	Primary industries—livestock drinking water	Primary industries—aquaculture and human consumption of aquatic foods
Public stormwater systems	X	X				
Surface waters in a water protection area (within the meaning of section 61 of the Act)	X	X	X	X	X	X
Underground waters as follows:						
(a) underground waters with a background TDS level of less than 1 200 mg/L			X	X	X	X
(b) underground waters with a background TDS level of 1 200 mg/L or more, but less than 3 000 mg/L				X	X	X
(c) underground waters with a background TDS level of 3 000 mg/L or more, but less than 13 000 mg/L					X	X

ANZECC & ARMCANZ (2000)

Chapter 4 LTV, STV

Chapter 9 LTV, STV

Must consider the end use of the water - agriculture

Table 4.2 Key environmental hazards, environmental endpoints and common effects on the environment when using recycled water for agricultural, municipal, residential and fire-control purposes

Hazard	Environmental endpoint	Effect or impact on the environment
Boron	Accumulation in soil	Plant toxicity
Cadmium	A low risk with respect to cadmium concentrations in recycled water, but cadmium already in soils can be made more readily available to plants if chloride concentrations increase. Chloride can be measured indirectly, but reliably, as salinity (see the salinity section below).	
Chlorine disinfection residuals	Plants	Direct toxicity to plants
	Surface waters	Toxicity to aquatic biota
Hydraulic loading (water)	Soil	Waterlogging of plants
	Groundwaters	Waterlogging of plants
	Groundwaters	Soil salinity (secondary)
Nitrogen	Soils	Nutrient imbalance in plants
	Soils	Pest and disease in plants
	Soils	Eutrophication of soils and effects on terrestrial biota
	Surface waters	Eutrophication
	Groundwaters	Contamination
Phosphorus	Soils	Eutrophication of soils and toxic effects on phosphorus sensitive terrestrial biota (native plants)
	Surface waters	Eutrophication
Salinity	Infrastructure	Salinity may cause rising damp or corrosion of assets; this can also arise from excessive hydraulic load (secondary salinity)
	Soils	Plants stressed from osmotic affects of soil salinity
	Soils	Contamination of soils by increasing plant availability of cadmium that is already in the soil
	Surface water	Increasing the salinity of fresh groundwaters
	Groundwater	Increasing the salinity of fresh surface waters
Chloride	Plants	Direct toxicity to plants when sprayed on leaves
	Soils	Plant toxicity via uptake through the root
	Surface water	Toxicity to aquatic biota
Sodium	Plants	Direct toxicity to plants when sprayed on leaves
	Soils	Plant toxicity via uptake through the root
	Soils	Soil structure decline due to sodicity

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others as outlined in ANZECC & ARMCANZ (2000) for irrigation

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Bolivar ASR research (led by CSIRO)

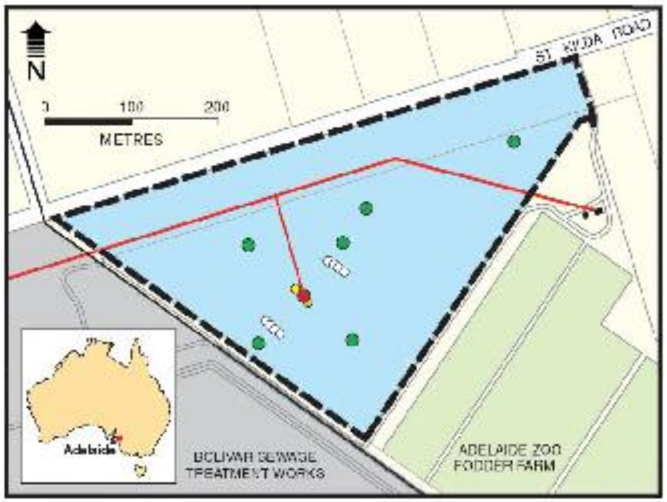
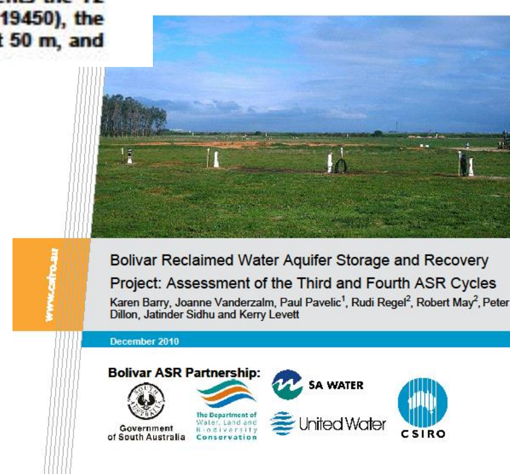
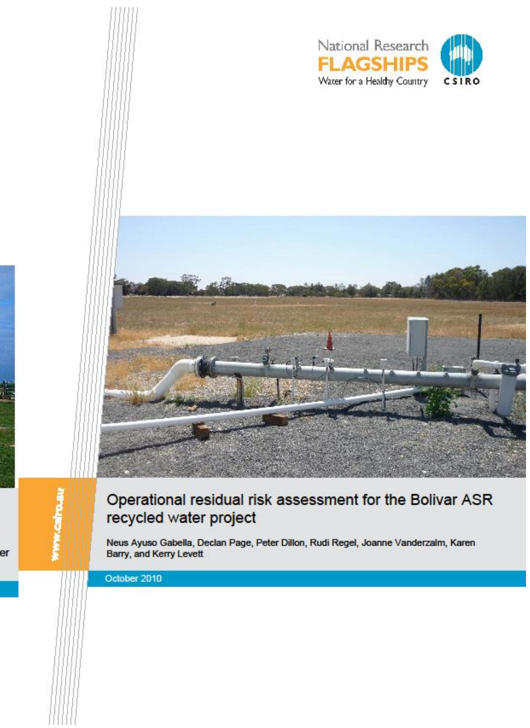


Figure 3 Location of wells and piezometers at the Bolivar site. The red dot represents the T2 ASR production well (#18777), the orange dot is the T2 observation well at 4 m (#19450), the yellow dot targets the T1 aquifer well (#19179), the white dots are T2 piezometers at 50 m, and green dots are observation wells at 75 m, 120 m and 300 m (from Barry *et al.*, 2009).





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Bolivar ASR research - overview

- 4 cycles of aquifer injection & recovery, into a single bore
- Numerous observations bores (4 m, T2, T1)
- Change in Bolivar WWT over the cycles
- Investigations:
  - Performance (injection rates, specific capacity, purge water management)
  - Hydraulic impacts
  - Salinity & recovery efficiency
  - Water quality in/ out & relative to agricultural requirements
  - Hydrogeological reactions (e.g. As, limestone dissolution)
  - Aquifer characterisation & capability (pump testing, storage volumes)
  - Column studies, mineralogy
  - Aquitard & bore stability
  - Targeted studies
- Research fed into drafting the national AGWR – MAR (2009)
- ~2009-2010 risk assessment as per AGWR undertaken for Bolivar

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Bolivar ASR research – water quality results

Sewage – maximal risk

- Drinking water: *ADWG (2004)*
- Environmental value: *ANZECC & ARMCANZ (2000) LTV, STV*
- Groundwater reference

Table A-1 Untreated wastewater quality summary.

	Unit	LOR	n	min	mean	median	max	95th p.	Period	ADWG	GW ref.	LTV Irrig.	STV Irrig.	WHO DW	Mean <GL
Physical characteristics															
Electrical Conductivity	dS/cm	0.001	188	0.022	2.0	2.0	2.6	2.3	05-2008		3.7	0.65 [1]	0.65 [1]		
Dissolved Oxygen	mg/L	0.1	406	<LOR	0.66	0.33	25	1.6	05-2008		0.3				
pH	pH units	0.1	191	6.8	7.3	7.3	7.8	7.6	05-2008	6.5-8.5	7.0	6-8.5	6-8.5		
Suspended Solids	mg/L	0.1	187	104	415	424	764	552	05-2008		5.0				
Total Dissolved Solids	mg/L	1	188	12	1103	1110	1420	1260	05-2008	500	2009				
Microbiological															
Cryptosporidium	oocysts/L	1	24	<LOR	326	28	5000	747	99-2000						
Giardia	cysts/L	1	24	<LOR	2720	345	26000	8355	99-2000						
Nutrients															
Ammonia as N	mg/L	0.005	186	22	44	45	54	51	05-2008	0.50	0.06	5 [2]	25-125 [2]		
Biological Oxygen Demand	mg/L	2	192	170	397	410	575	495	05-2008						
Chemical Oxygen Demand	mg/L	50	106	299	819	803	1390	1180	03-2008						
Phosphorus - Total	mg/L	0.005	72	8	12	12	17	14	03-2008		0.024	0.05 [3]	0.8-12		
Total Kjeldahl Nitrogen as N	mg/L	0.05	72	48	66	66	87	77	03-2008		0.064				
Metals, metalloids and halogens															
Aluminium Total	mg/L	0.005	92	0.010	5.2	4.7	15	11	03-2008	0.2	0.028	5	20	0.2	
Antimony Total	mg/L	0.0005	89	<LOR	0.0010	0.00090	0.0023	0.0016	03-2008	0.003				0.02	
Arsenic Total	mg/L	-	92	0.0005	0.0015	0.0010	0.0050	0.0040	03-2008	0.					
Barium Total	mg/L	0.0005	17	0.0070	0.26	0.069	1.4	1.3	06-2007						
Beryllium Soluble	mg/L	0.0005	47	<LOR	<LOR	<LOR	0.0025	<LOR	06-2008						
Beryllium Total	mg/L	0.0005	7	<LOR	<LOR	<LOR	<LOR	<LOR	2006						
Boron Soluble	mg/L	0.04	74	0.23	0.39	0.35	1.4	0.55	03-2008						
Cadmium Total	mg/L	0.0002	92	0.00025	0.00042	0.00025	0.0036	0.00095	03-2008	0.					
Chromium Total	mg/L	0.003	92	<LOR	0.06	0.03	2.3	0.09	03-2008						
Cobalt Total	mg/L	0.0005	92	<LOR	0.0014	0.0013	0.0031	0.0025	03-2008						
Copper Total	mg/L	0.001	92	0.023	0.17	0.15	0.42	0.36	03-2008						

[1] For sensitive crops; moderately sensitive 0.65-1.3, moderately tolerant 1.3-2.9. See ANZECC-ARMCANZ guidelines for a detailed tolerance of diffe

[2] Values given for the sum of all the inorganic nitrogen (ammonia + ammonium + nitrite + nitrate)

[3] To avoid biologging in irrigation equipment.

[4] For very sensitive crops; sensitive 0.5-1, moderately sensitive 1-2. See ANZECC-ARMCANZ guidelines for a detailed tolerance of different crops to

Recycled water/ injectant

Table A-4 Recovered water quality summary.

	Unit	LOR	n	min	mean	median	max	95th p.	Period	ADWG	GW ref.	LTV Irrig.	STV Irrig.	WHO DW	Mean <GL.
Physical characteristics															
Electrical Conductivity	dS/cm	0.001	25	1.9	2.2	2.3	2.6	2.5	02-2005		3.7	0.65 [1]	0.65 [1]		
Dissolved Oxygen	mg/L	0.1	6	<LOR	<LOR	<LOR	<LOR	<LOR	02-2005		0.30				
Eh	mV SHE		6	-11	56	77	94	93	02-2005		65				
pH	pH units	0.1	17	7.3	7.8	7.9	8.2	8.2	02-2005	6.5-8.5	7.0	6-8.5	6-8.5		
Total dissolved solids	mg/L	1	25	1027	1230	1238	1403	1383	02-2005	500	2009				
Temperature	°C	-	6	12	18	18	23	22	02-2005		25				
Turbidity	NTU	0.1	25	0.76	2.7	1.8	7.9	7.2	02-2005	5.00	12				
Major ions and SAR															
Alkalinity as Calcium Carbonate	mg/L	4	2	193			211		02-2005		305				
Bicarbonate	mg/L	4	25	235	275	272	350	317	02-2005		325				
Calcium	mg/L	0.1	25	53	69	66	86	83	02-2005		150				
Chloride	mg/L	4	25	364	467	458	611	584	02-2005	250	976	175 [2]			
Cyanide as CN - Total	mg/L	0.05	2	<LOR			<LOR		2005	0.08					
Magnesium	mg/L	0.3	25	34	41	41	50	50	02-2005		85				
Potassium	mg/L	1	25	33	43	44	48	48	02-2005		13				
SAR	SAR units	-	25	6.5	7.4	7.4	8.3	8.3	02-2005		8	2 [2]			
Sodium	mg/L	0.5	25	263	313	312	370	358	02-2005	180	503	115 [2]			
Sulphate	mg/L	1.5	25	166	196	195	233	220	02-2005	500	297				
Nutrients															
Ammonia as N	mg/L	0.005	19	0.0060	1.7	1.6	7.4	3.2	02-2005	0.50	0.060	5 [3]	2		
DOC	mg/L		14	6.6	13	12	38	22	02-2005		2.9				
Nitrate + Nitrite as N	mg/L	0.005	21	0.0090	0.67	0.64	2.1	1.9	2002		0.0034	5 [3]	2		
Nitrate as N	mg/L	0.005	12	<LOR	0.32	0.032	1.9	1.5	2002	11	0.00050	5 [3]	2		
Nitrite as N	mg/L	0.005	9	0.0070	0.26	0.021	1.5	1.1	2002	0.91	<0.005	5 [3]	2		
Phosphorus - Dissolved	mg/L	0.005	14	0.34	0.90	0.80	1.6	1.6	02-2005						
Phosphorus - Total	mg/L	0.005	25	0.37	0.86	0.76	1.9	1.6	02-2005		0.024	0.05 [4]			

[1] For sensitive crops; moderately sensitive 0.65-1.3, moderately tolerant 1.3-2.9. See ANZECC-ARMCANZ guidelines for a detailed tolerance of different crops.

[2] A value superior to the referred one can cause foliar damage in sensitive crops.

[3] Values given for the sum of all the inorganic nitrogen (ammonia + ammonium + nitrite + nitrate).

Operational Residual Risk Assessment for the Bolivar ASR recycled water project Page 43

ASR recovered water

	Unit	LOR	n	min	mean	median	max	95th p.	Period	ADWG	GW ref.	LTV Irrig.	STV Irrig.	WHO DW	Mean <GL
Microbiological															
Bacteria															
Enterococci *	ufc/100mL	1	1		<LOR				2008						
Ent/F.Strep - Presumptive *	ufc/100mL	1	1		<LOR				2008						
E. coli - Presumptive	cfu/100 mL	1	244	<LOR	0.20	<LOR	19	<LOR	05-2008	0	0				
Faecal coliforms *	ufc/100mL	1	2	6			20		04-2008						
Faecal Streptococci *	ufc/100mL	1	1		<LOR				2008						
Total Coliforms *	ufc/100mL	1	1		110				2004						
Protozoa															
Cryptosporidium – confirmed #	/50 L		13/255	1	4.42	4	12.25	9.8	05-2009						
Giardia - confirmed ##	/50 L		2/255	3	7.75	7.75	12.25	12.025	05-2009						
Cryptosporidium - Presumptive **	cysts/L	0.02	72	<LOR	0.047	0.040	0.16	0.089	07-2008						
Giardia - Presumptive **	cysts/L	0.02	72	<LOR	0.069	0.060	0.20	0.16	07-2008						
Disinfection															
Chlorine - Free	mg/L	0.1	436	<LOR	1.6	1.5	5.8	3.0	05-2008	5					
Chlorine - Total	mg/L	0.1	436	0.10	2.5	2.0	7.0	4.0	05-2008					5	
Nutrients															
Ammonia as N *	mg/L	0.005	34	0.017	1.1	0.32	5.5	3.7	02-2008		0.06	5 [3]	25-125 [3]		
DOC *	mg/L		22	9.6	17	18	24	21	02-2008		2.9				
Nitrate + Nitrite as N	mg/L	0.005	55	0.29	7.9	6.3	14	14	07-2008		0.0034	5 [3]	25-125 [3]		
Nitrate as N	mg/L	0.005	76	0.28	8.6	8.1	14	14	07-2008	11	0.00050	5 [3]	25-125 [3]	11	
Nitrite as N	mg/L	0.005	59	<LOR	<LOR	<LOR	0.009	<LOR	07-2008	0.91	<LOR	5 [3]	25-125 [3]	0.91	
Phosphorus - Dissolved *	mg/L	0.005	22	0.016	2.2	2.0	5.9	3.8	02-2008						
Phosphorus - Total	mg/L	0.005	10	0.69	2.2	2.3	3.5	3.4	07-2008		0.02	0.05 [4]	0.8-12		
TKN as N	mg/L	0.05	11	2.0	3.0	2.6	5.3	4.7	07-2008		0.06				
TOC *	mg/L		34	10	16	14	26	21	02-2008		0.48				
Metals, metalloids and halogens															
Aluminium Total	mg/L	0.005	17	0.010	0.11	0.044	0.68	0.44	07-2008	0.2	0.028	5	20	0.2	
Arsenic Soluble *	mg/L	-	3	0.0020	0.0023	0.0020	0.0030	0.0029	2008		0.0043				
Arsenic Total	mg/L	-	17	0.0010	0.0017	0.0010	0.0040	0.0032	07-2008	0.007	0.0047	0.1	2	0.01	

Operational Residual Risk Assessment for the Bolivar ASR recycled water project Page 39

Bolivar ASR CSIRO research – targeted studies

- Arsenic speciation/ mobilisation
- Disinfection by-products
- Trace organics
- Pathogens

APPENDIX D: HYDROCHEMISTRY CALCULATIONS

The aquifer sediments are a potential source for a number of elements that are considered in the irrigation guidelines (ANZECC & ARMCANZ, 2000). While some of these species are present at higher concentrations in the injectant than in the ambient groundwater, the soluble concentration present in the injectant is negligible when compared to the insoluble component within the aquifer sediments (Table D-1).

Aquifer storage can also lead to release of species from the sediments to the aqueous phase through hydrogeochemical processes such as calcite dissolution, pyrite oxidation and reductive iron(III) oxide dissolution. The overall impact on the concentration of metals/metalloids in the recovered water quality can be evaluated by examining the quality of recovered water in comparison to guideline values and quantifying the dominant reaction processes within the system.

Based on 11 core samples taken from the T2 aquifer, calcite constitutes 74%, quartz 18%, ankerite 5%, with traces of hematite, microcline and albite (Vanderzalm *et al.*, 2006). Organic carbon, iron and manganese constitute low percentages.

Assuming a porosity of 0.45 and a bulk density of 1.5 g/cm^3, 1 L of water occupies 2.17 L of aquifer, and 3.3 Kg of aquifer material. Using aluminium as an example, 1L of water is in contact with 4,290 mg of aluminium (3.3 Kg aquifer material x 1,300 mg/Kg Al) which is far greater that than added through injection of reclaimed wastewater during ASR injectantion. Then calculating e.g. Aluminium, the average aluminium concentration in the sediments is; if 1 L of water occupies 3.3 Kg of aquifer material, then it can be potentially released from the sediments. So, the water injected in the aquifer introduces a very low amount of aluminium compared to what it can be dissolved from the aquifer. However, the aquifer immediately surrounding the ASR well could be at risk of metal accumulation if all of the injected metal accumulate around the point of injection and are not effectively removed through backwashing procedures.

Calculating for the other metals cited in Section 4.2, the results are summarized in Table D-1.

Table D-1 Potential release of metals from the aquifer

Metal	Injectant (mg metal/L injected water)	Ambient groundwater (mg metal /L ambient groundwater	Aquifer sediments (mg metal /Kg sediment)	Estimated concentration in contact with 1L of injectant (mg)
Aluminium	0.11	0.028	1300	4290
Cadmium	0.00058	< 0.0002	1	3.3
Chromium	0.0031	< 0.003	33	109
Copper	0.011	< 0.001	1	3.3
Nickel	[illegible]	[illegible]	7	23

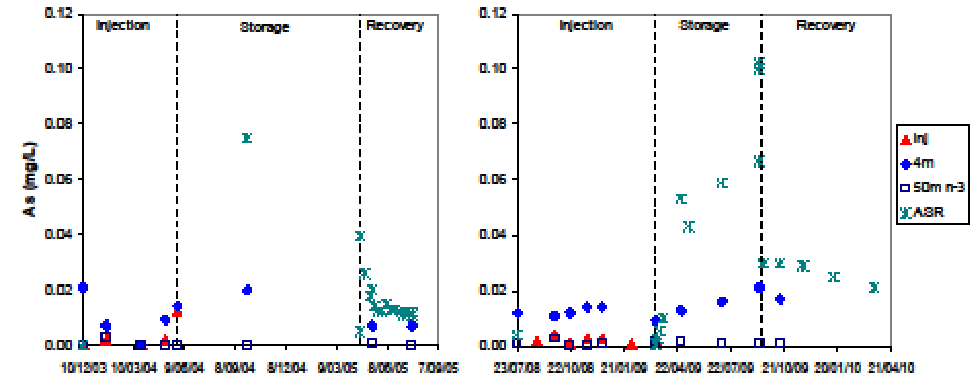

Figure 27 Arsenic behaviour over duration of the third and fourth ASR cycles at Bolivar

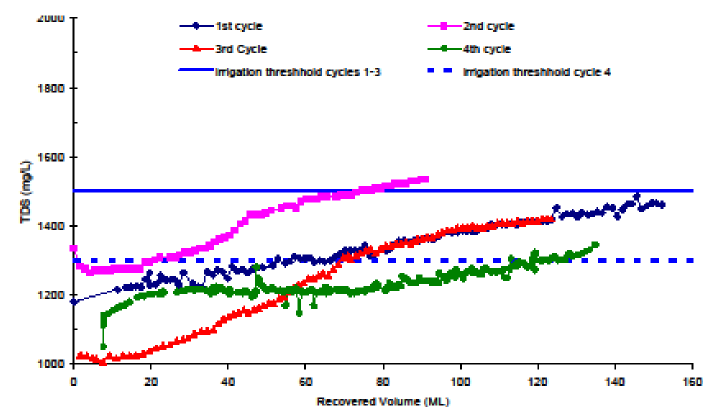

Figure 22 Total dissolved solids (TDS) increases during the three recovery phases in relation to volume recovered

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Bolivar ASR research – hazard risk assessment

Table 3 Maximal risk assessment regarding the hazards identified in the MAR guidelines

MAR Hazards	Human endpoints –		Environment endpoints –		
	Crop consumption	Ingestion of sprays	Irrigation – crops	Irrigation – soil	Aquifer
1. Pathogens	H	H	H	H	H
2. Inorganic chemicals	H	H	H	H	H
3. Salinity and sodicity	L	L	H	H	L
4. Nutrients: nitrogen, phosphorous and organic carbon	L	L	H	H	H
5. Organic chemicals	L	H		H	H
6. Turbidity and particulates	L	L		H	H
7. Radionuclides	U	U			U
8. Pressure, flow rates, volumes and groundwater levels					H
9. Contaminant migration in fractured rock and karstic aquifers					U
10. Aquifer dissolution and stability of well and aquitard					H
11. Aquifer and groundwater-dependent ecosystems					H
12. Energy and greenhouse gas considerations					U

H: high risk, one or more of the parameters related to the hazard have a mean value higher than the guideline value for the end point.
U: uncertain risk – further investigations required.
L: low risk, all parameters related to the hazard have a mean value lower than the guideline value for the end point.
White: the hazard does not apply to the end point.

Preventive measures:

Recycled water supply
+
ASR management
+
Agricultural sector

Table 4 Residual risk assessment regarding the hazards identified in the MAR guidelines

MAR Hazard	Human endpoints –		Environment endpoints –		
	Crop consumption	Ingestion of sprays	Irrigation – crops	Irrigation – soil	Aquifer
1. Pathogens	L	L	L	L	L
2. Inorganic chemicals	L	L	L	L	L
3. Salinity and sodicity	L	L	L	L	L
4. Nutrients: nitrogen, phosphorous and organic carbon	L	L	L	L	L
5. Organic chemicals	L	L		L	L
6. Turbidity and particulates	L	L		L	L
7. Radionuclides	L	L			L
8. Pressure, flow rates, volumes and groundwater levels					L
9. Contaminant migration in fractured rock and karstic aquifers					L
10. Aquifer dissolution and stability of well and aquitard					L
11. Aquifer and groundwater-dependent ecosystems					L
12. Energy and greenhouse gas considerations					L

H: high risk, one or more of the parameters related to the hazard have a mean value higher than the guideline value for the end point.
U: uncertain risk – further investigations required.
L: low risk, all parameters related to the hazard have a mean value lower than the guideline value for the end point.
White: the hazard does not apply to the end point.

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Future presentations related to MAR

Table 5.1 Summary of key hazards in source water, groundwater and aquifer materials for managed aquifer recharge projects, with examples of specific hazards and preventive methods

Hazard	Origin[a]	Examples	Preventive measures	Relevant section of document[d]
Pathogens	S, (G)	Viruses	Adequate aquifer residence time	5.1
Inorganic chemicals	G, A, S	Arsenic	Control Eh during recharge (avoid mobilisation)[b]	5.2
Salinity and sodicity	G, (S)	Salinity	Increase volume of freshwater recharged	5.3
Nutrients	S, (G)	Nitrogen	Pretreat water (eg activated sludge)	5.4
Organic chemicals	S, (G)	Pesticides	Exclude prone subcatchments	5.5
Turbidity and particulates	S, (G)	Suspended solids	Pretreat water (eg wetland)	5.6
Radionuclides	G, A, (S)	Alpha radiation	Aquifer selection (avoidance)	5.7
Pressure, flow rates, volumes and levels	S	Waterlogging	Reduce injection pressure	5.8
Contaminant migration in fractured rock and karstic aquifers	S, (G)	PAHs[c]	Pretreat or extend attenuation zone (exclusion)	5.9
Aquifer dissolution and aquitard and well stability	S, A	Excess sand recovery	Control pH of source water (avoid dissolution)	5.10
Impacts on groundwater-dependent ecosystems	S, A	Levels outside historical range	Avoid proximity to groundwater-dependent ecosystems	5.11
Greenhouse gases	S	Excessive energy use	Substitute passive treatments for active	5.12

a A = aquifer minerals; G = groundwater ; S = source water for recharge; Brackets show possible secondary source.
b Eh = a measure of redox potential — the propensity for oxidation and reduction reactions.
c PAHs = polycyclic aromatic hydrocarbons.
d See also the Phase 1 guidelines, the augmentation guidelines (NRMMC–EPHC–NHMRC 2008) and the fresh and marine water quality guidelines (ANZECC–ARMCANZ 2000a).

- CSIRO (27/1/16)
  - Bolivar ASR research
- Glen Harrington (10/2/16)
  - Principles of hydrogeology
  - Types of aquifers
  - Bore construction
  - Pump testing & aquifer characterisation
  - Hydrogeological modelling (pressure, solute transport)
  - MAR
  - NAP