

MAR Essentials Workshop

Thurs 26th – Fri 27th Oct 2017

Perth Mercure Hotel, 10 Irwin Street

A joint initiative of:



ICE WaRM

International Centre of Excellence
in Water Resources Management

The International Centre of Excellence in Water Resources Management

(ICE WaRM)

and



**NATIONAL CENTRE FOR
GROUNDWATER
RESEARCH AND TRAINING**

The National Centre for Groundwater Research and Training

(NCGRT)

International Centre of Excellence in Water Resources Management (ICE WaRM)
Level 4, 33 King William St
GPO Box 860
Adelaide
South Australia 5001
Tel: +61 8 8236 5200
Fax: +61 8 8236 5236
e-mail: training@icewarm.com.au
Web: www.icewarm.com.au

Copyright© WaterEd Australia

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical photocopying, recording or otherwise, without prior permission.

Printed and Bound in Australia by the International Centre of Excellence in Water Resources Management.

MAR Essentials Workshop™

Thurs 26th – Fri 27th Oct 2017
Mercure Hotel Perth: 10 Irwin St, PERTH WA

A joint initiative of ICE WaRM & NCGRT

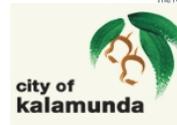


ICE WaRM
International Centre of Excellence
in Water Resources Management



**NATIONAL CENTRE FOR
GROUNDWATER**
RESEARCH AND TRAINING

In association with Managed Recharge; Wallbridge Gilbert Aztec; WA Water Corporation; CSIRO; WA Dept of Water and Environmental Regulation; City of Mandurah; Pennington Scott; FMG; UWA; Shire of Kalamunda.



Government of Western Australia
Department of Water and Environmental Regulation



Time	Session No	Topics	Presenter
DAY 1 CHAIR: Karen Johnston			
8.15 – 8.30		Registration, <i>arrival tea & coffee</i>	
8.30 - 8.35		Workshop Introductions	
8.35 – 9.15	1	Managed Aquifer Recharge (MAR): Introduction and Overview	Karen Johnston <i>Managed Recharge</i>
9.15 – 9.45	2	Potential for MAR in the Perth Peel Region	Don McFarlane <i>UWA</i>
9.45 – 10.30	3	Is MAR an Option? Preliminary Feasibility Assessment	Karen Johnston <i>Managed Recharge</i>
10.30 – 11:00		Morning Tea	
11.00 – 11:30	4	Kwinana – Feasibility of MAR using Recycled Water	Mike Donn <i>CSIRO</i>
11.30 – 12.15	5	Will it Work? Technical Viability Assessment	Russ Martin <i>WGA</i>
12.15 – 12:30		<i>Discussion</i>	<i>All</i>
12.30 – 1:15		Lunch	
1.15 – 1.45	6	Minderoo – Viability of Enhanced Recharge using an Upside-Down Weir	Don Scott <i>Pennington Scott</i>
1:45 – 2.30	7	Setting up a MAR Site – Implementation and Testing	Russ Martin <i>WGA</i>
2.30 – 3.10	8	Perry Lakes – Aquifer Recharge using Infiltration Galleries Infiltration Galleries at CSIRO Floreat: FIG and MARRO projects.	Don McFarlane <i>UWA</i>
3.10 – 3.30		Afternoon Tea	
3.30 – 4.15	9	Moving to an Operational Scheme – Issues and Management	Russ Martin <i>WGA</i>
4.15 – 5:00	10	Chichester Range MAR Scheme – Injecting for almost 10 years	Jordin Barclay <i>FMG</i>
5.00 – 6.00		<i>Complimentary happy hour drinks and nibbles with the presenters</i>	

MAR Essentials Workshop™

Thurs 26th – Fri 27th Oct 2017
Mercure Hotel Perth: 10 Irwin St, PERTH WA

A joint initiative of ICE WaRM & NCGRT

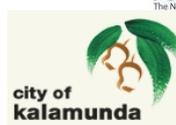


ICE WaRM
International Centre of Excellence
in Water Resources Management



**NATIONAL CENTRE FOR
GROUNDWATER**
RESEARCH AND TRAINING

In association with Managed Recharge; Wallbridge Gilbert Aztec; WA Water Corporation; CSIRO; WA Dept of Water and Environmental Regulation; City of Mandurah; Pennington Scott; FMG; UWA; Shire of Kalamunda.



Government of Western Australia
Department of Water and Environmental Regulation



**AUSTRALIAN
WATER**
ASSOCIATION

Time	Session No	Topics	Presenter
DAY 2 CHAIR: Karen Johnston			
8.30 – 8.45		<i>Arrival tea & coffee</i>	
8.45 – 9.00	11	Review previous day	
9.00 – 10.00	12	Beenyup – MAR as a Water Resource Management Tool	Simon Higginson Water Corporation WA
10.00am		Board Bus and 10am sharp (<i>Morning Tea on board- packed by Mercure</i>)	
10.30 – 12:00	13	Field Visit: Beenyup Groundwater Replenishment Scheme	Simon Higginson Water Corporation WA
12.00 – 12.30	14	Field Visit: Hartfield Park Municipal Scale ASR	Karen Johnston Managed Recharge
12.30 – 1:00		Lunch (<i>packed by Mercure</i>)	
1.00 – 1.30	15	Field Visit: Hartfield Park Municipal Scale ASR	Daniel Nelson Shire of Kalamunda
1.30 – 2:45	16	Field Visit: Kwinana, Spectacles Wetlands	Mike Donn CSIRO Don McFarlane UWA
2:45 – 3:15	17	Field Visit: Meadow Springs/Gordon Rd WWTP	Karen Johnston Managed Recharge Don McFarlane UWA
3:15 – 3:30		Afternoon Tea (<i>packed by Mercure</i>)	
3:30 – 4:30	18	Field Visit: Caddadup WWTP/Ocean Rd Reserve	Dale Robinson City of Mandurah
4:30 – 5:30		<i>Discussion on return bus ride</i>	All Presenters
6:00		<i>End of Workshop</i>	

MAR Essentials Workshop

Perth Thurs 26th - Fri 27th Oct 2017

Presenter	Biography
 <p data-bbox="261 779 524 842">Karen Johnston <i>Managed Recharge</i></p>	<p data-bbox="618 352 1520 842">Karen Johnston is a Principal Hydrogeologist/Geochemist with 21 years' experience in Managed Aquifer Recharge (MAR). She has recently established a groundwater consultancy specialising in MAR, Managed Recharge, after 20 years with the well-regarded hydrogeological consulting firm, Rockwater. Karen completed her Master of Science researching geochemical reactions in aquifer storage and recovery (ASR) systems, working on the internationally recognised Andrew's Farm project in South Australia with the CSIRO. She commenced working with the Water Corporation in 1999, investigating the potential use of ASR in Perth's integrated water supply system, helping to establish two state of the art ASR trial sites, Jandakot and Mirrabooka, which were direct precursors to the Beenyup Groundwater Replenishment Scheme, for which Karen is the lead hydrogeological consultant. Karen has extensive experience in assessing the feasibility and viability of potential aquifer replenishment schemes, and was responsible for hydrogeological assessment and implementation of the Hartfield Park stormwater recharge scheme at Forrestfield; the first and only municipal ASR project of its kind in Western Australia, as well as wastewater re-use projects such as the Ocean Road scheme in Mandurah.</p> <p data-bbox="618 873 1143 898">karen.johnston@managedRecharge.com.au</p>
 <p data-bbox="237 1297 548 1398">Russell Martin <i>Wallbridge Gilbert Aztec (WGA)</i></p>	<p data-bbox="618 940 1528 1350">Russell has over 30 years of experience as a geologist/hydrogeologist with extensive Public and Private sector experience in groundwater resources management, water sensitive urban design and integrated catchment water management. Russell has been involved in the delivery and review of over 60 stormwater harvesting and Managed Aquifer Recharge projects nationally and internationally and is recognised as a global expert in this highly specialised area of hydrogeology and engineering. He possesses considerable practical experience in the investigation, design, delivery, and operation of MAR systems including infiltration basins and aquifer storage and recovery bores. He has delivered several workshops both for local operators and in international forums and served on several State and National water resources technical working committees. Russell authored the first monograph on clogging during managed aquifer recharge under the International Association of Hydrogeologists (IAH) MAR Working Group and is currently compiling volume 2.</p> <p data-bbox="618 1377 886 1402">RMartin@wga.com.au</p>
 <p data-bbox="245 1755 540 1818">Simon Higginson <i>Water Corporation WA</i></p>	<p data-bbox="618 1535 1520 1703">Simon Higginson is the Senior MAR Advisor at the Water Corporation of Western Australia, with 12 years' experience in managed aquifer recharge research and operations. Simon currently leads the hydrogeological investigations, risk assessment process for regulatory approvals and well-design team to progress the Beenyup Groundwater Replenishment Scheme, which will inject 90ML/day of recycled water to Perth confined aquifers.</p> <p data-bbox="618 1730 1143 1755">Simon.Higginson@watercorporation.com.au</p>

MAR Essentials Workshop

Perth Thurs 26th - Fri 27th Oct 2017

Presenter	Biography
 <p>Don McFarlane <i>University of WA</i></p>	<p>Don McFarlane BSc MSc PhD has over 30 years experience in land and water research and management. He has led the Soils and Catchment Hydrology groups in the WA Department of Agriculture, been a Director of both water research and management in the state water agency, and coordinated WA water research in CSIRO, Floreat. He is currently an Adjunct Professor at UWA and part-time consultant. His main areas of interest are currently managed aquifer recharge, urban hydrology under climate change, and remote sensing. His research papers have been cited more than 2000 times and he has won the CSIRO Chairman Medal for his research.</p> <p>don.mcfarlane@outlook.com</p>
 <p>Michael Donn <i>CSIRO</i></p>	<p>Mike is a Senior Experimental Scientist with CSIRO and has 18 years' experience as an environmental chemist in the agriculture and environment sectors. Since joining CSIRO in 2006 he has applied his biogeochemical expertise to assess processes influencing groundwater and surface water quality. Since 2012 Mike has been involved with a number of managed aquifer recharge research projects largely focusing on assessment of the geochemical impacts on infiltration and injection of treated wastewater into the superficial and confined aquifers in Perth. More recently Mike has been involved in the assessment of the potential for MAR to support industry in the Kwinana area contributing to a regional scale pre-feasibility study. He is currently involved in MAR projects associated with Groundwater Replenishment, assessment wastewater disposal through infiltration and further MAR feasibility studies in the Kwinana area.</p> <p>Michael.Donn@csiro.au</p>
 <p>Daniel Nelson <i>City of Kalamunda</i></p>	<p>Daniel Nelson has a diversity of experience and expertise in water management, sporting and recreation facilities, groundwater extraction and sustainability. He was the driving force in the development of the Shire's Managed Aquifer Recharge Project and has proven experience in finding alternative water sources to ensure the long term sustainability of maintaining recreation sites. Daniel has been with the Shire of Kalamunda for the past 9 years and is currently employed as the Coordinator of Project Delivery. He has also held senior positions in the field of Irrigation, Parks and Reserves. Daniel is currently on the state executive team for Irrigation Australia limited (IAL WA Region). He holds formal qualifications in Irrigation, Project Management, and Outdoor Education and has completed study with the National Centre for Groundwater Research and Training. Daniel is passionate about working towards water saving solutions while continuing to provide green public open space.</p> <p>Daniel.Nelson@kalamunda.wa.gov.au</p>

MAR Essentials Workshop

Perth Thurs 26th - Fri 27th Oct 2017

Presenter	Biography
 <p>Dale Robinson <i>City of Mandurah</i></p>	<p>Dale has a Degree in Environmental Management from Murdoch University and is the Groundwater Conservation Officer for the City of Mandurah, Western Australia. Dale's experience has been through previous work with the private sector for 7 years and then 8 years with State and Local Government. He has worked extensively in the area of air and water monitoring for industrial processes. Through his current role he has successfully project managed and delivered the City of Mandurah's Caddadup Managed Aquifer Recharge Scheme, for irrigation of active open space. The success of this Managed Aquifer Recharge Scheme has led the City of Mandurah to expand on its water recycling schemes and research Aquifer Storage and Recovery, for a variety of active and recreational open space.</p> <p>Dale.Robinson@mandurah.wa.gov.au</p>
 <p>Don Scott <i>Pennington Scott</i></p>	<p>Don is the Managing Director and Hydrogeologist at Pennington Scott Pty Ltd, a groundwater company with three parts: Groundwater Consulting; Wellfield contracting (borefield installation and management) and an R&D company, Northwater, developing remote borefield automation. Over the past ten years this team has fluctuated between 12 and 30 staff including hydrogeologists, hydrologists, geophysicists, numerical modellers and engineers. Don and his colleagues have built a solid reputation managing deep geothermal bores, regional water exploration and borefield development, strategic mine water management and remote automated borefield management. In addition to his consulting work, Don also lectures at the University of Western Australia and the Australian Groundwater School in Hydrogeology, Mine Dewatering, Strategic Mine Water Management, Groundwater Exploration & Development and Bore Construction. Involved deeply in the industry, Don is on the Australian Drilling Industry Association (ADIA) Adjudicating Committee and runs the Screens and Gravel Pack Course for the ADIA's DrillSkill.</p> <p>don@penningtonscott.com.au</p>
 <p>Jordin Barclay <i>FMG</i></p>	<p>Jordin is a Principal Hydrogeologist for Fortescue Metals Group's Chichester Operations. He has been working for FMG for over 5 years and has been a mining hydrogeologist for 15 years at various mine sites in Western Australia, United States, Mexico and throughout Canada. The Chichester Operations (Cloudbreak mine and Christmas Creek mine) operate the second largest mine dewatering system in the world and is situated adjacent to the Fortescue Marsh, an endorheic basin with hypersaline groundwater at depth. The Chichester Operations are currently approved for 200 gegalitres per annum abstraction, most of which is re-injected in order to maintain the water levels adjacent to the Fortescue Marsh. Jordin has been involved in all stages of MAR at the Chichesters, including approvals, bore and infrastructure construction, testing, operations and maintenance.</p> <p>jbarclay@fmgl.com.au</p>

Managed Aquifer Recharge

INTRODUCTION & OVERVIEW

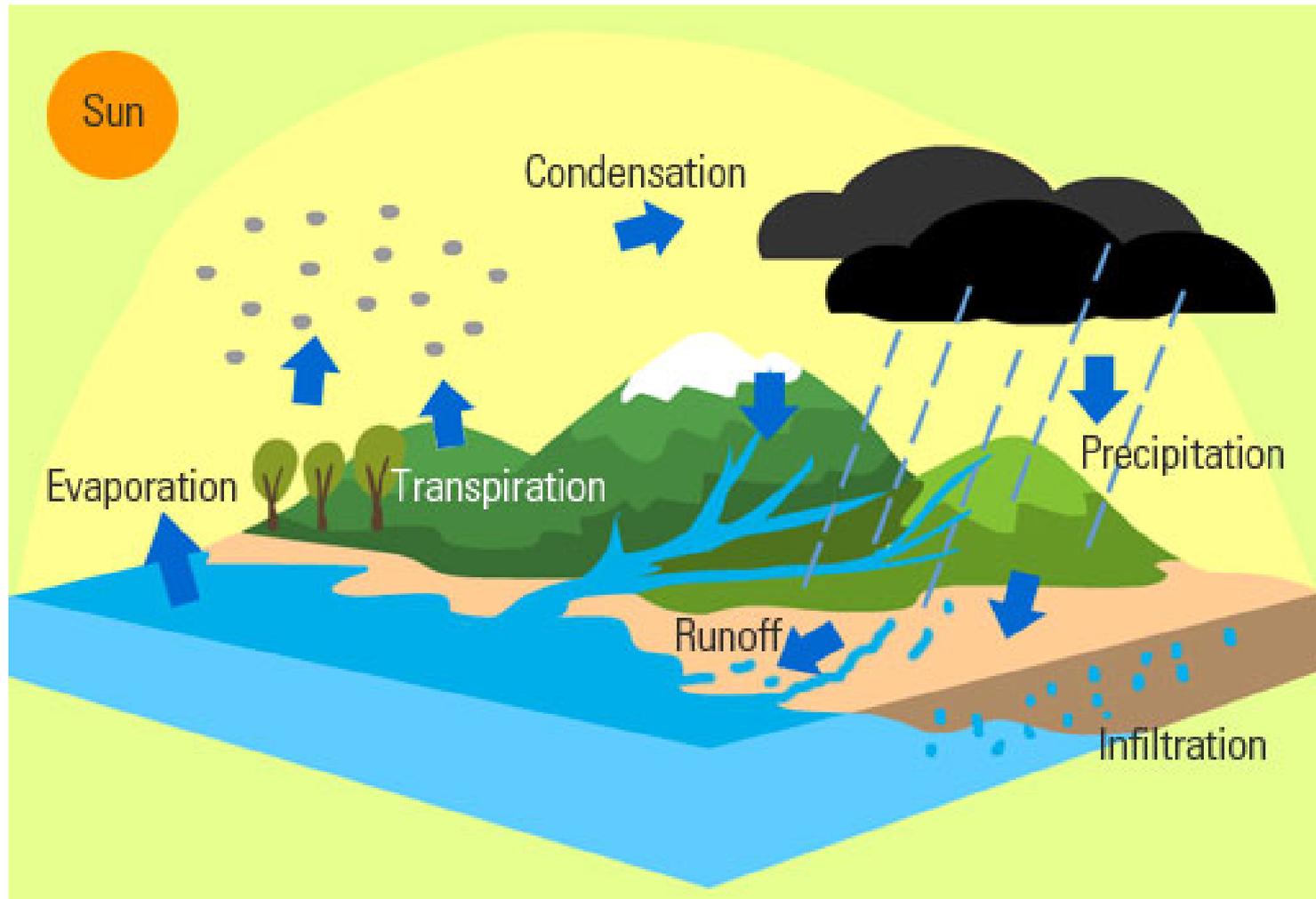
Karen Johnston – Managed Recharge

Level 24 Allendale Square | 77 St Georges Terrace | PERTH WA 6000

0407 198 398 | karen.johnston@managedrecharge.com.au | www.managedrecharge.com.au

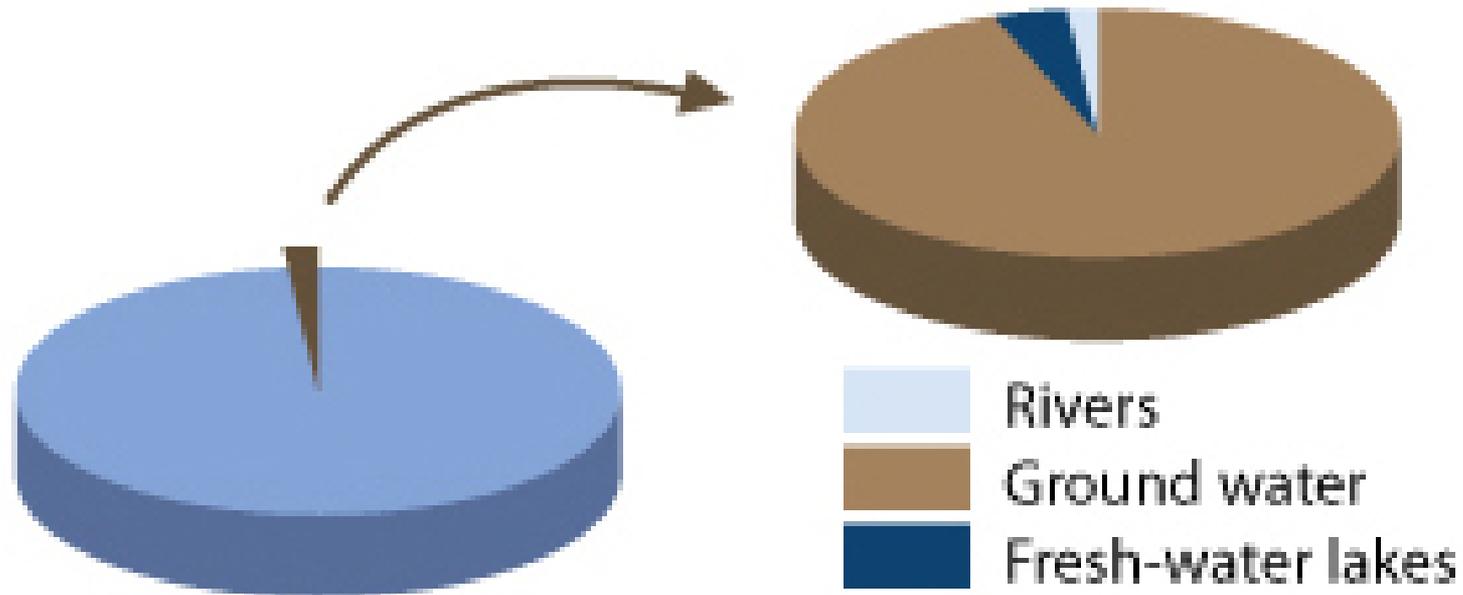
Groundwater

ITS PLACE IN THE WATER CYCLE AND LOCAL ENVIRONMENT



The water cycle

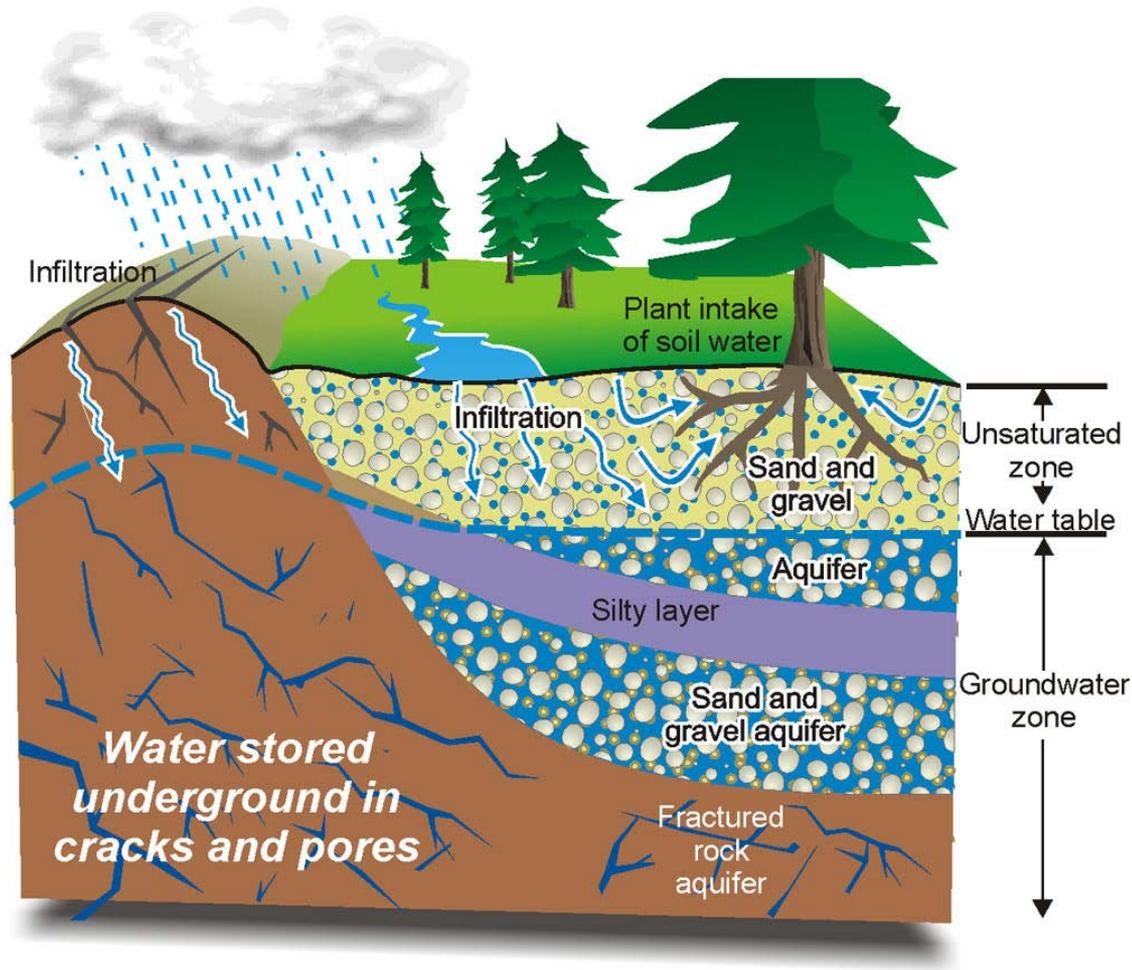
Water usable by humans



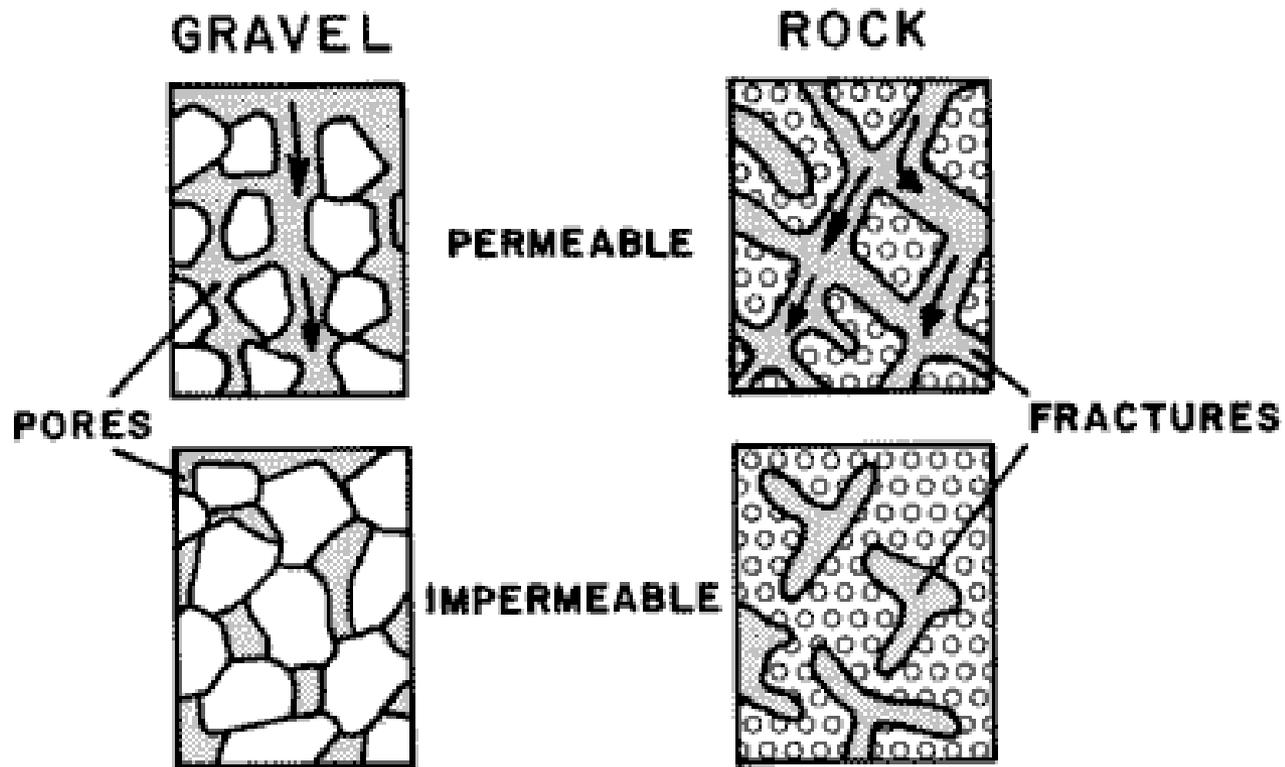
All water on Earth

- 0.3% is usable by humans
- 99.7% is **unusable** by humans

Distribution of water on Earth



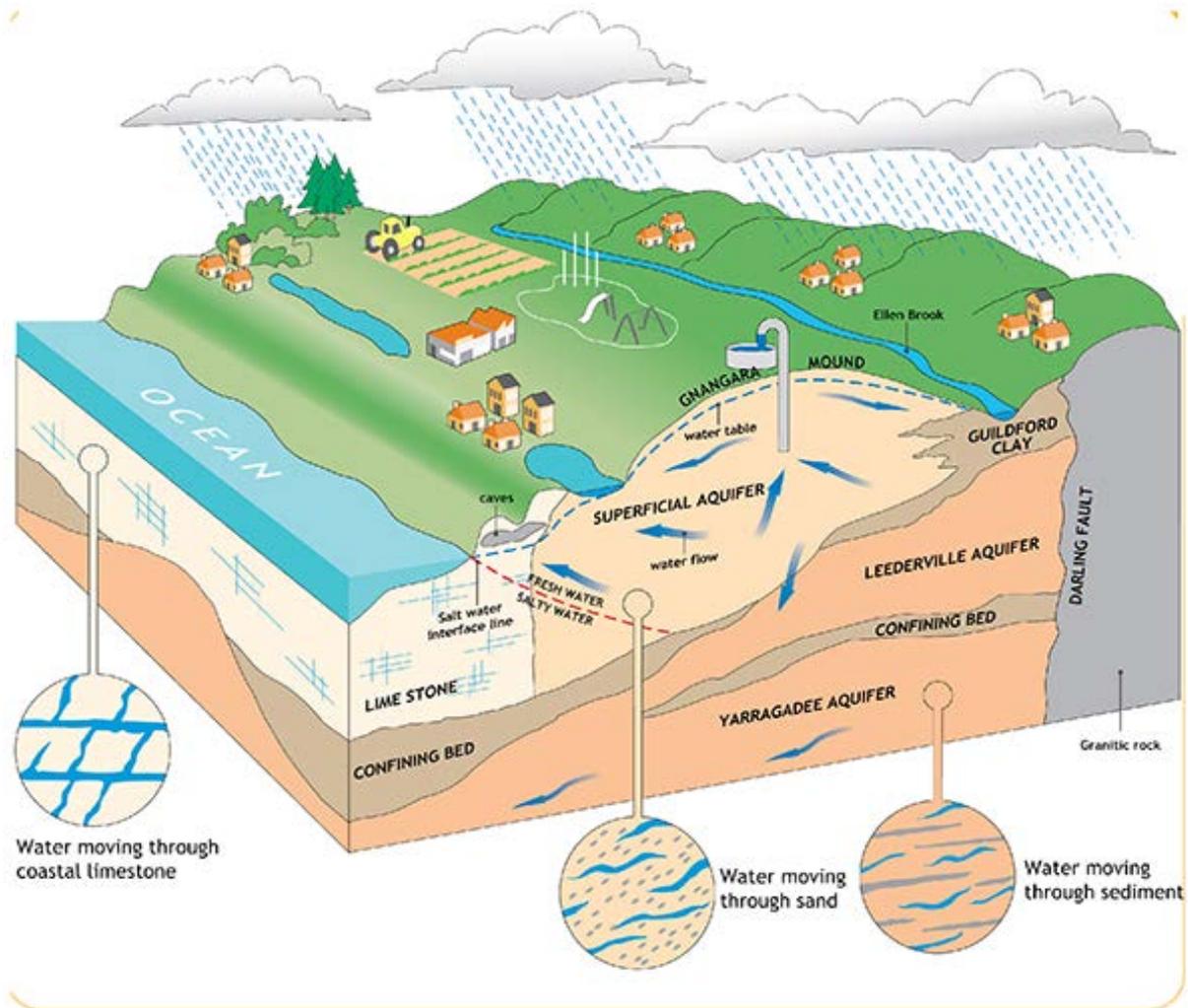
Groundwater is that water that infiltrates to the sub-surface



Permeability – how easy it is for water to move through the ground.

Not to scale:

- Superficial average 50 m thick
- Leederville up to 300 m thick
- Yarragadee up to 1000 m thick.



North Perth's Groundwater system: Gnangara Mound



Groundwater is used to water many of Perth's gardens and sporting reserves, and provides up to 80% of our mains water supply.



Groundwater can be seen at the surface in many of Perth's lakes

Managed Aquifer Recharge

INNOVATIVE GROUNDWATER MANAGEMENT TOOL

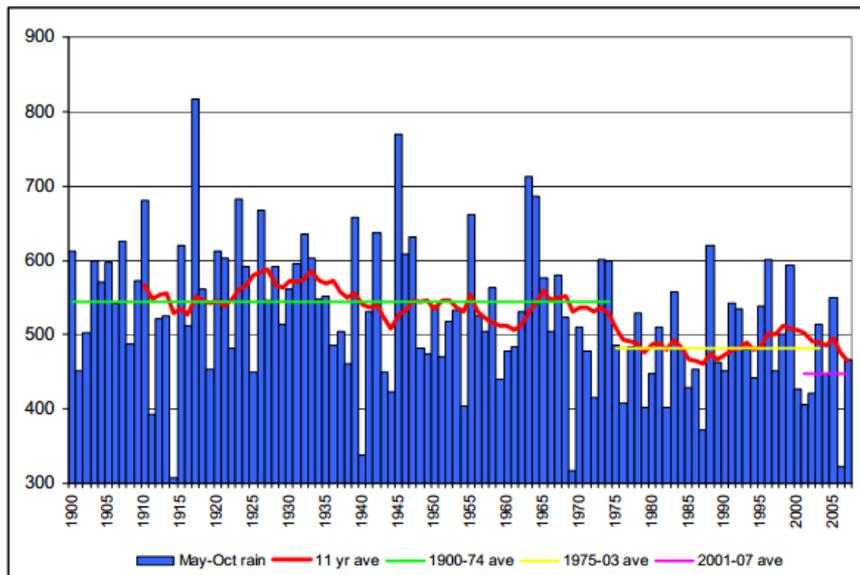


Figure 2 Trends in May to Oct rainfall (mm) in the South West

Declining winter rainfall:

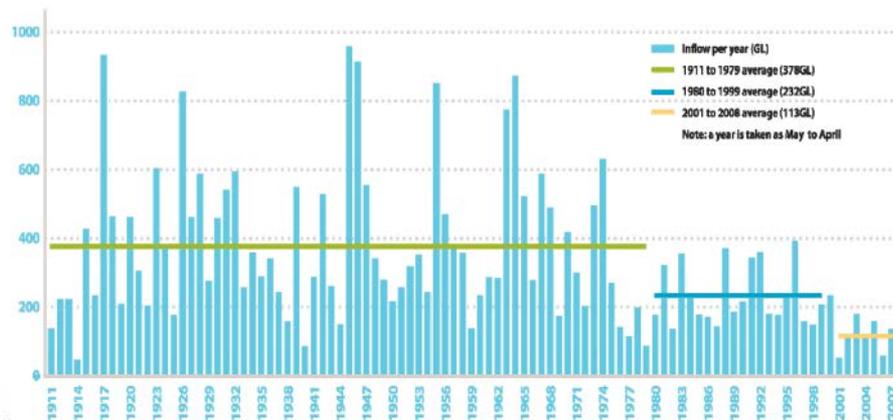


Figure 3 Annual streamflows into Perth dams - GL/y (Source: Water Corporation)

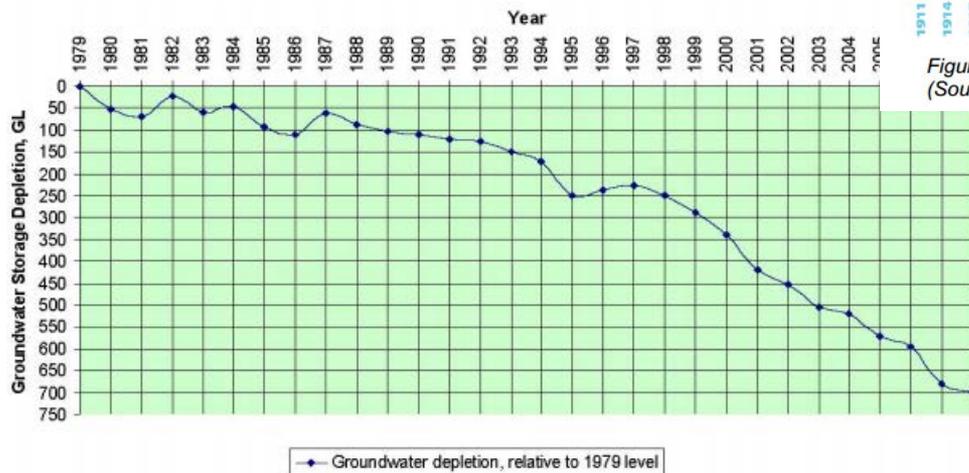
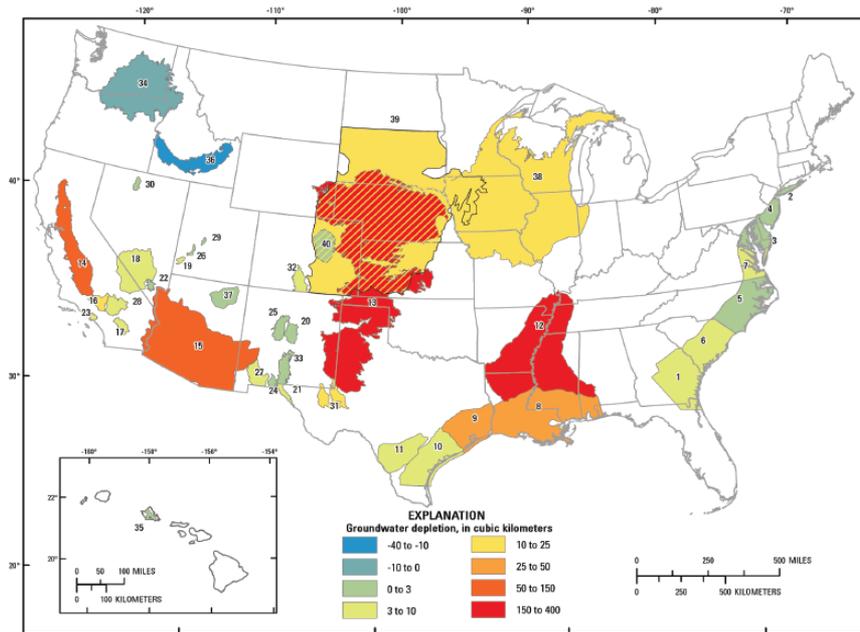


Figure 4 Reduction in groundwater storage in the Gnangara superficial aquifer

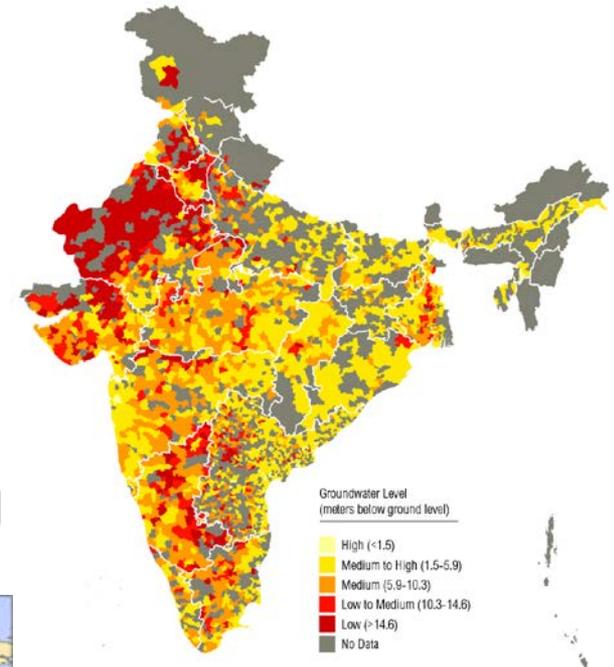
Reduced dam inflow and Shallow groundwater storage



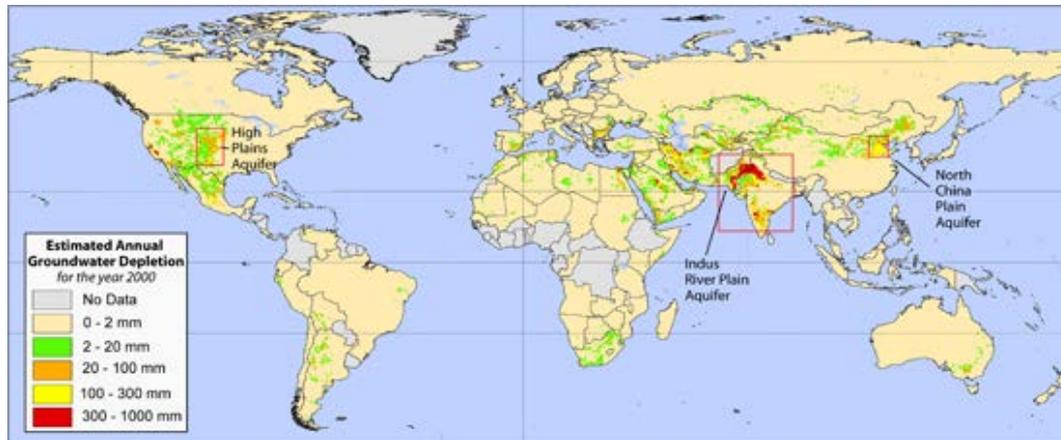
Base from U.S. Geological Survey digital data, 1972, 1:2,000,000
Albers Equal-Area Conic Projection
Standard parallels 29° 30' N and 46° 30' N, central meridian 96° 00' W

Figure 2. Map of the United States (excluding Alaska) showing cumulative groundwater depletion, 1900 through 2008, in 40 assessed aquifer systems or subareas. Index numbers are defined in table 1. Colors are hatched in the Dakota aquifer (area 39) where the aquifer overlaps with other aquifers having different values of depletion.

54%
of India's
Ground-
water
Wells Are
Decreasing



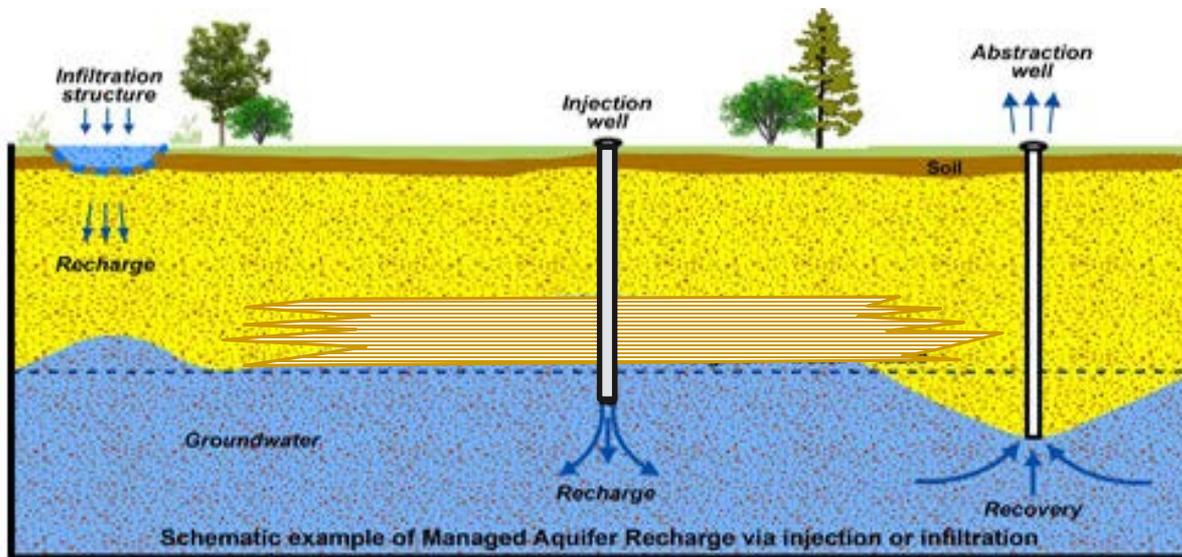
WORLD RESOURCES INSTITUTE



Strategic directions set by DoW for sustainable management of the regions water resources

- Assumes climate likely to become dryer
- Facilitate use of alternative water sources
- Create water sensitive cities and towns
- Reduce allocation limits where the system is in decline
- Modify water pricing and implement water trading
- Support alternative sources for fit-for-purpose use
- ✓ Support large-scale recycled water schemes, particularly via MAR
- ✓ Supports MAR to bolster groundwater levels and as an alternate water supply

Managed Aquifer Recharge (MAR)



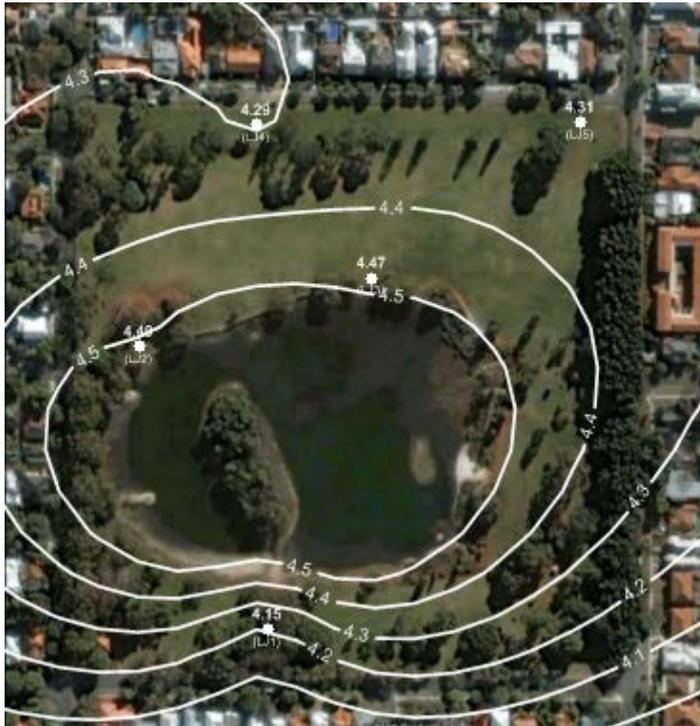
Source: Department of Water website (modified)

“... recharging an aquifer under controlled conditions to store water for later abstraction or to achieve environmental benefits.”

*Department of Water,
2011*

MAR: Not so new...

Has been happening by default in Perth since European settlement in 1829:



Lake Jualbup – Shenton Park

Source: Rockwater (2012)

- Urban lakes/sumps receive stormwater from local drains
- Water infiltrates to shallow aquifer » recharge mound
- Local councils/residents install bores for garden irrigation
- Estimated ~200 GL/yr (Dillon 2016)
- Currently not licenced or managed under DoW MAR policy

Wastewater Infiltration and Reuse

Emerging Water Source in WA:



- Largely infiltrated with minimal re-use
- Environmental concerns » reduced infiltration capacity (DER)
- Recovery bores » municipal water supply for sports fields
- DoW (now DWER) » regulate extraction using MAR policy

Operational Example – City of Mandurah

Improved urban amenity



Meadow Springs and Ocean Rd Reserve

Capturing water from Gordon Rd and Caddadup WWTP's

Water piped 1.3 km from bores at WWTP – specially constructed, low yield bores to minimise saline water up-coning and maximise recovery efficiency.

Modifying the Natural Environment

Increasing infiltration potential



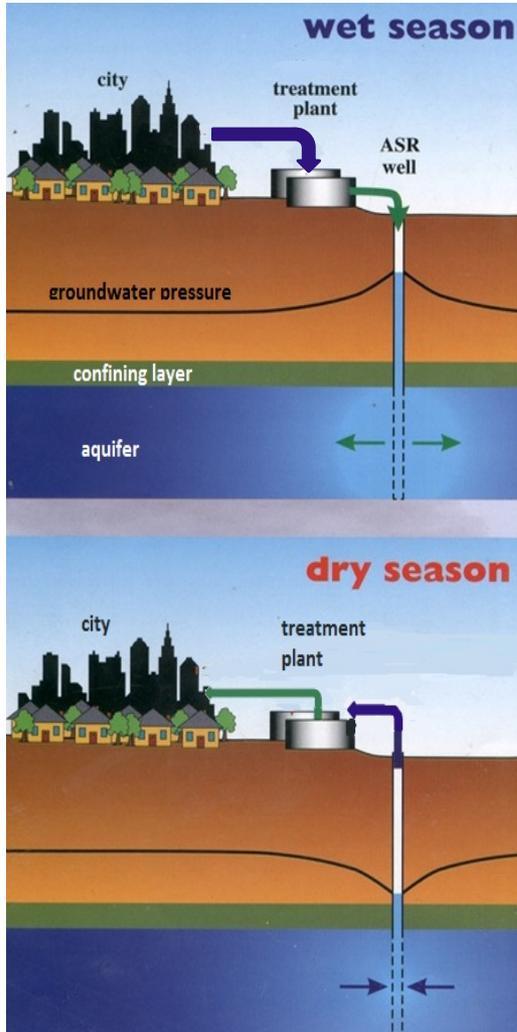
Burdekin Delta Scheme – oldest MAR in Australia

- Increase natural recharge
- Increase groundwater availability
- Large storage – minimum evaporation
- Protects against saline intrusion



“Upside down weir” Minderoo, Ashburton River

Aquifer Storage and Recovery (ASR)



Injection and recovery of water from the same bore:

- Capture water that otherwise may have gone to waste
- Local storage using minimal land area
- No evaporative loss
- Replenish depleted aquifers
- Improve groundwater quality

Cost effective solution to water storage

The volume stored via this ASR bore each winter is ten times the volume of the two tanks behind.



ASR bore: Cocoa, Florida, USA

Stormwater Harvesting and Reuse

Urban Catchment:

- “Stormwater harvesting and storage via MAR has great potential in Perth...”
(DoW/GHD 2008)
- Feasibility assessment in Murray Region:
 - ASR using Cattamarra aquifer
 - 20 – 100 GL storage available(DoW 2011)
- Shire of Murray ASR trial under construction at Nambelup Industrial Area

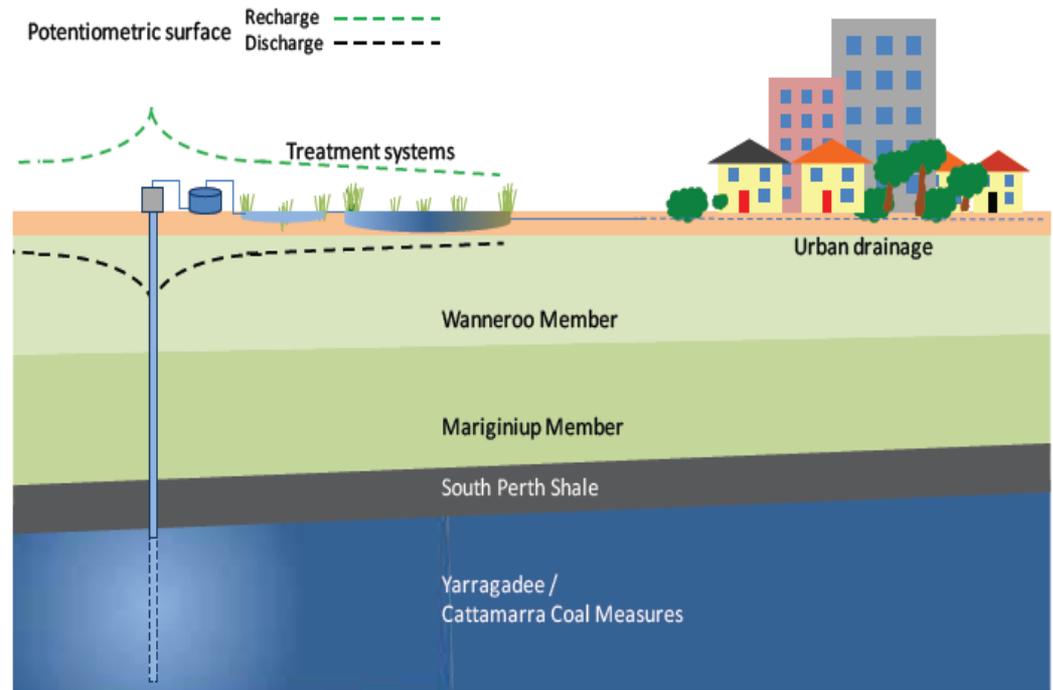
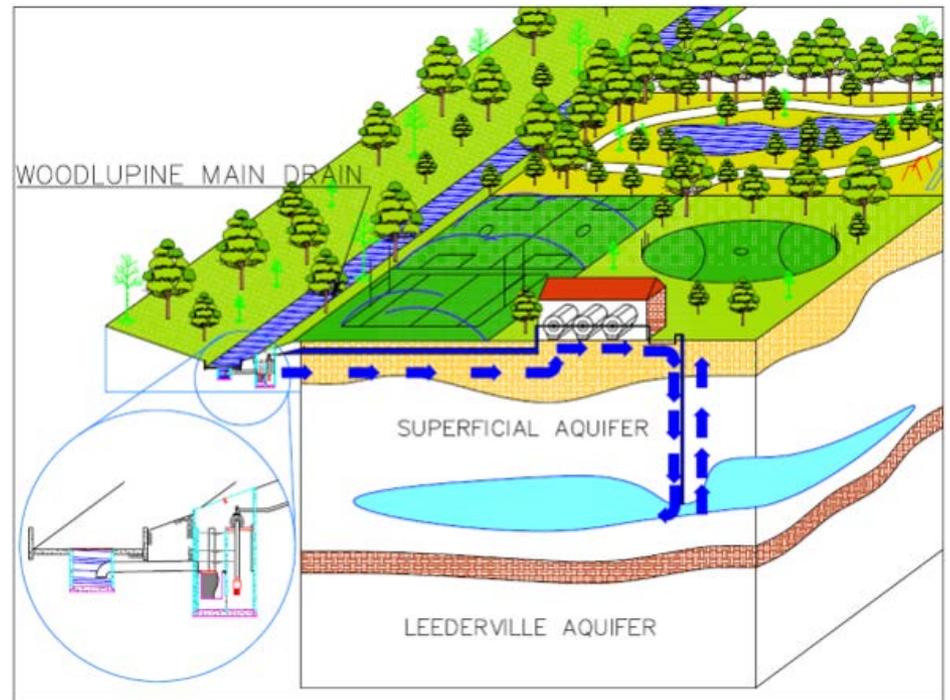


Figure 3.1 Conceptual diagram of an ASR scheme in the study area

Hartfield Park – Municipal Scale ASR

Demonstration Site

- Additional 50 ML/year required for irrigation
- 230 ML/year available drainage water
- High yield bores \gg available aquifer
- Trial suggests 150 ML/yr additional water



Aquifer Storage Transport and Recovery (ASTR)



Images supplied – Water Corporation

Beenyup Groundwater Replenishment Scheme: recharge recycled water to Perth's confined aquifers

- 3 year Groundwater Replenishment Trial
- Followed risk management process of National Guidelines
- Extensive community and government regulator consultation
- Detailed site characterisation:
 - Hydrogeology (aquifer characteristics and response)
 - Water quality (CSIRO)
- Moving to Stage 1 – recharge 14 GL/yr due to commence 2017
- Further upgrade to 28 GL/yr underway.

Environmentally Sustainable Water Disposal

Aquifer Re-injection of Surplus Dewatering Water – Mining and Construction



Goldfields Mine Site Re-injection
Borefield - fractured rock aquifer.



- Long term projects – FMG, Olympic Dam
- Trials – paleochannel recharge, Mulga Rock

SOME POTENTIAL BENEFITS OF MAR

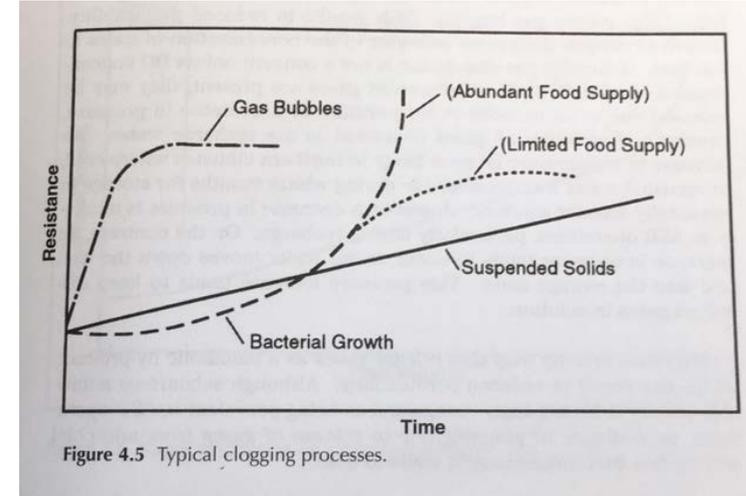
- Provide an alternative “fit for purpose water source through wastewater and/or stormwater recycling.
- Balance seasonal demands
- Water quality improvement
- Replenishment of coastal aquifers to reduce threat of seawater intrusion
- Reduce stress on groundwater dependent ecosystems
- Reduce drainage runoff to rivers and ocean



Maintaining water levels
in groundwater dependent
ecosystems

SOME POTENTIAL RISKS OF MAR

- Recovery efficiency
 - Background groundwater quality
 - High aquifer transmissivity
- Groundwater mounding
 - GDE's
 - Infrastructure
- Water quality degradation
 - Salinisation
 - Metal mobilisation
 - Introduction of contaminants
- Clogging
 - Infiltration basins/galleries
 - Recharge bores

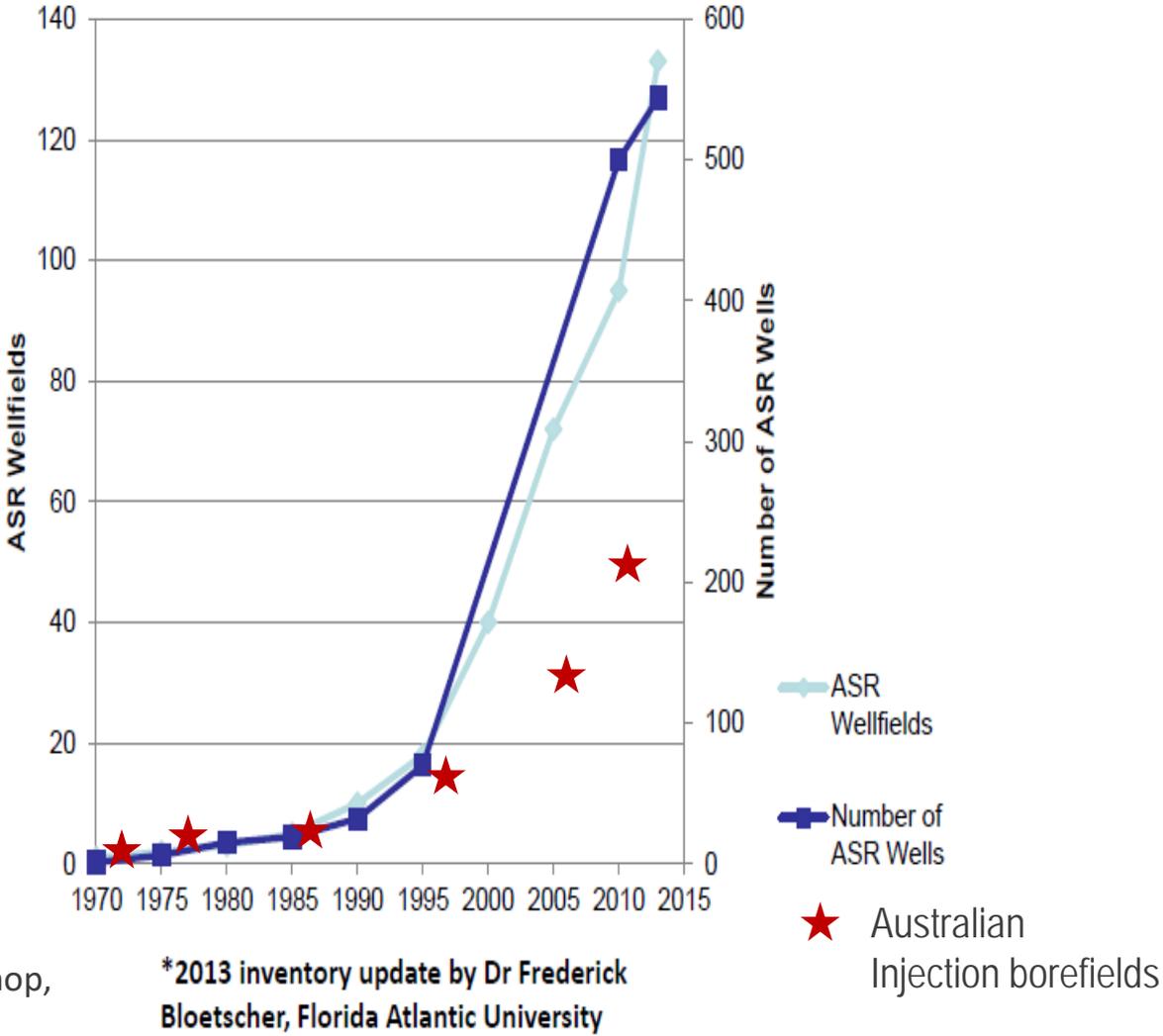


Inorganic precipitation of iron oxides



Snapshot of MAR in Australia – CSIRO 2015

Historical Development of ASR in United States and Australia



Modified from Pyne ASR workshop, ISMAR 8 Beijing 2013

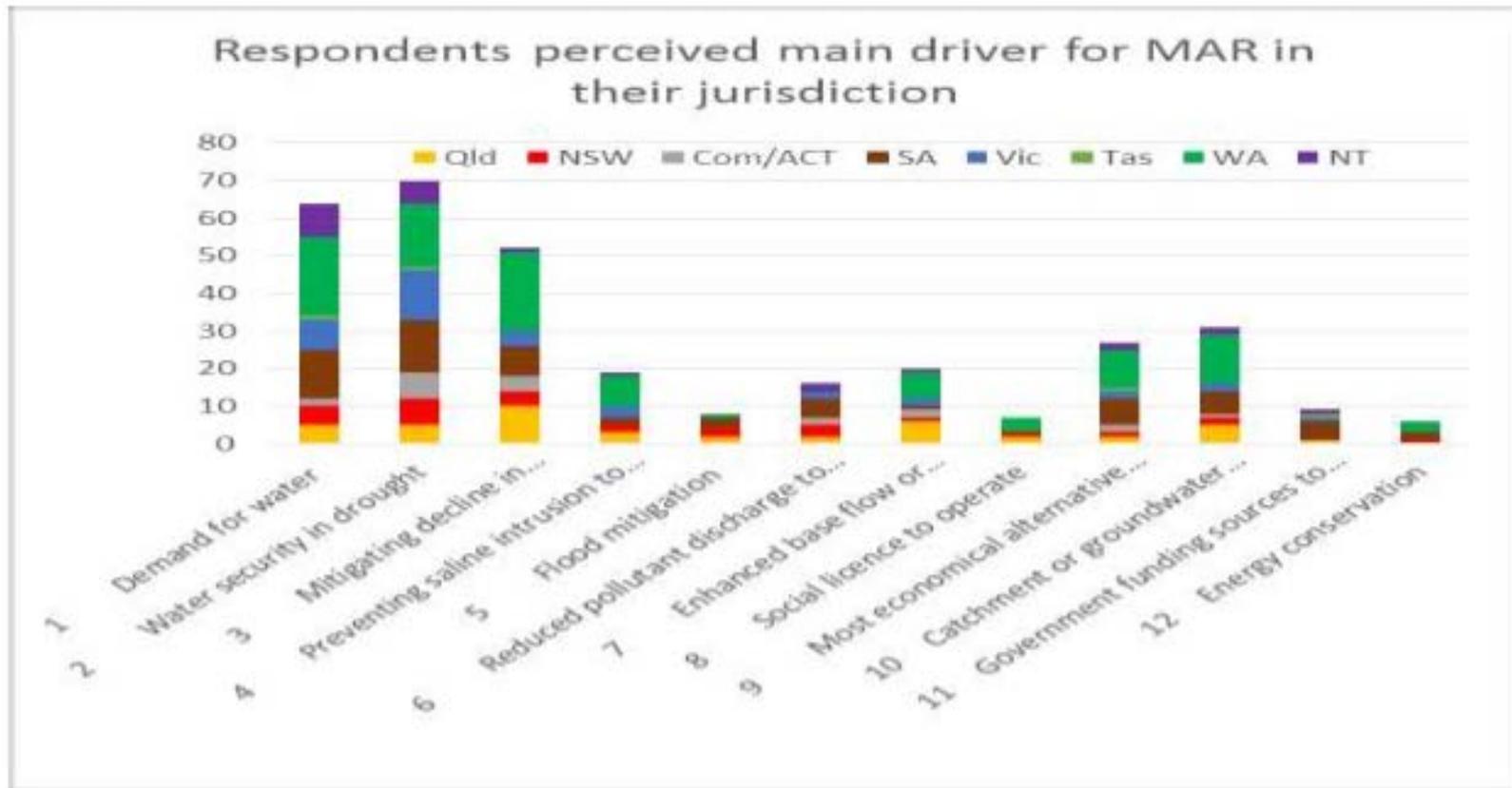


Figure 1. The main drivers for MAR perceived by 135 Australian respondents in a survey May-July 2015.

Source: Dillon, 2016

NATIONAL WATER QUALITY MANAGEMENT STRATEGY

AUSTRALIAN GUIDELINES 24 FOR WATER RECYCLING: MANAGING HEALTH AND ENVIRONMENTAL RISKS (PHASE 2)

MANAGED AQUIFER RECHARGE

JULY 2009



Natural Resource Management Ministerial Council
Environment Protection and Heritage Council
National Health and Medical Research Council



Government of Western Australia
Department of Water

Operational policy 1.01 – Managed aquifer recharge in Western Australia

Looking after all our water needs

Questions?

Karen Johnston – Managed Recharge

Level 24 Allendale Square | 77 St Georges Terrace | PERTH WA 6000

0407 198 398 | karen.johnston@managedrecharge.com.au | www.managedrecharge.com.au

The potential for managed aquifer recharge in the Perth-Peel region

**Dr Don McFarlane, Adjunct Professor
School of Agriculture and Environment
University of Western Australia**

**MAR Essentials
Workshop
Perth**

26th October 2017

The talk will cover

- Why the Swan Coastal Plain is suited to MAR
- The need for MAR right now
- Water supply options for MAR
 - Stormwater
 - Treated wastewater
 - Mining/industrial wastewater flows (in some areas)
- Soil-aquifer ability to accept MAR water
- Piping versus MAR
- Conclusions

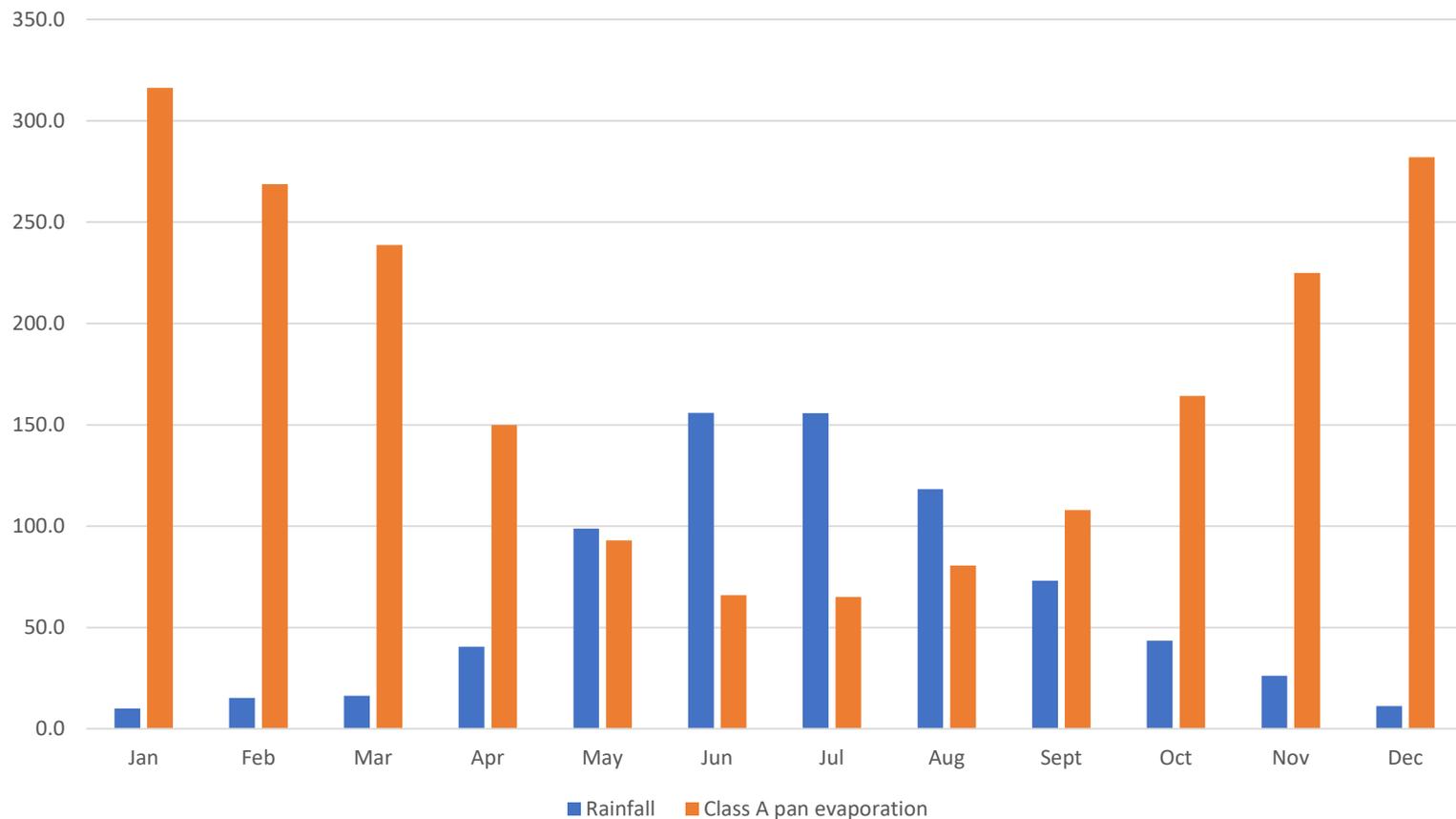
Seasonal distribution of rainfall and potential evaporation

(Source: BoM website accessed September 2017)



Rainfall only exceeds potential evaporation in 4 months
Total potential evaporation is 2.8 x rainfall; deficit is almost 1300mm

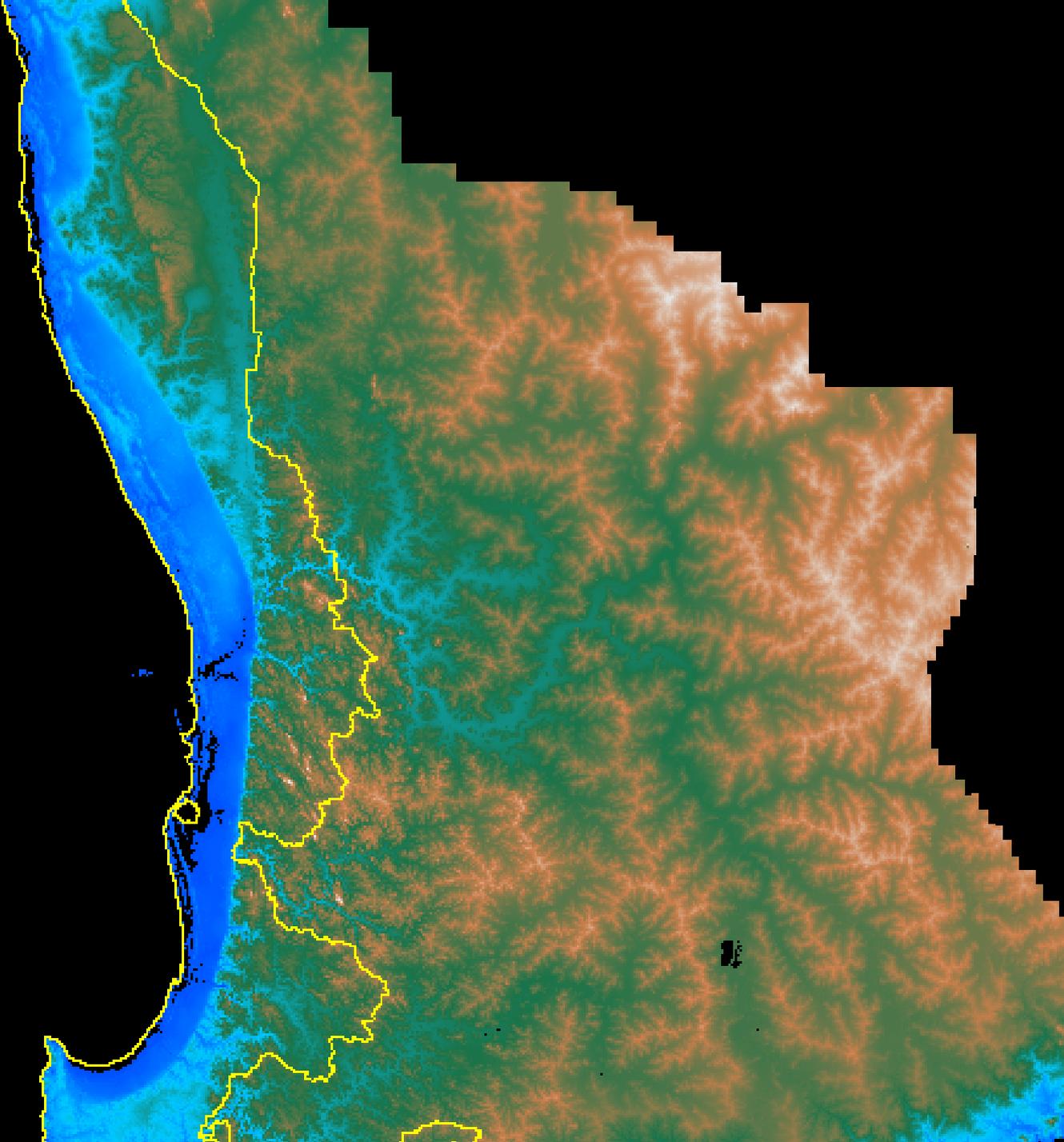
Perth Airport Rainfall 1944-2017 Annual = 765mm
Class A pan evaporation 1981-2017 Annual = 2058mm



The Swan Coastal Plain portion of the Perth Basin has an almost complete lack of drainage features

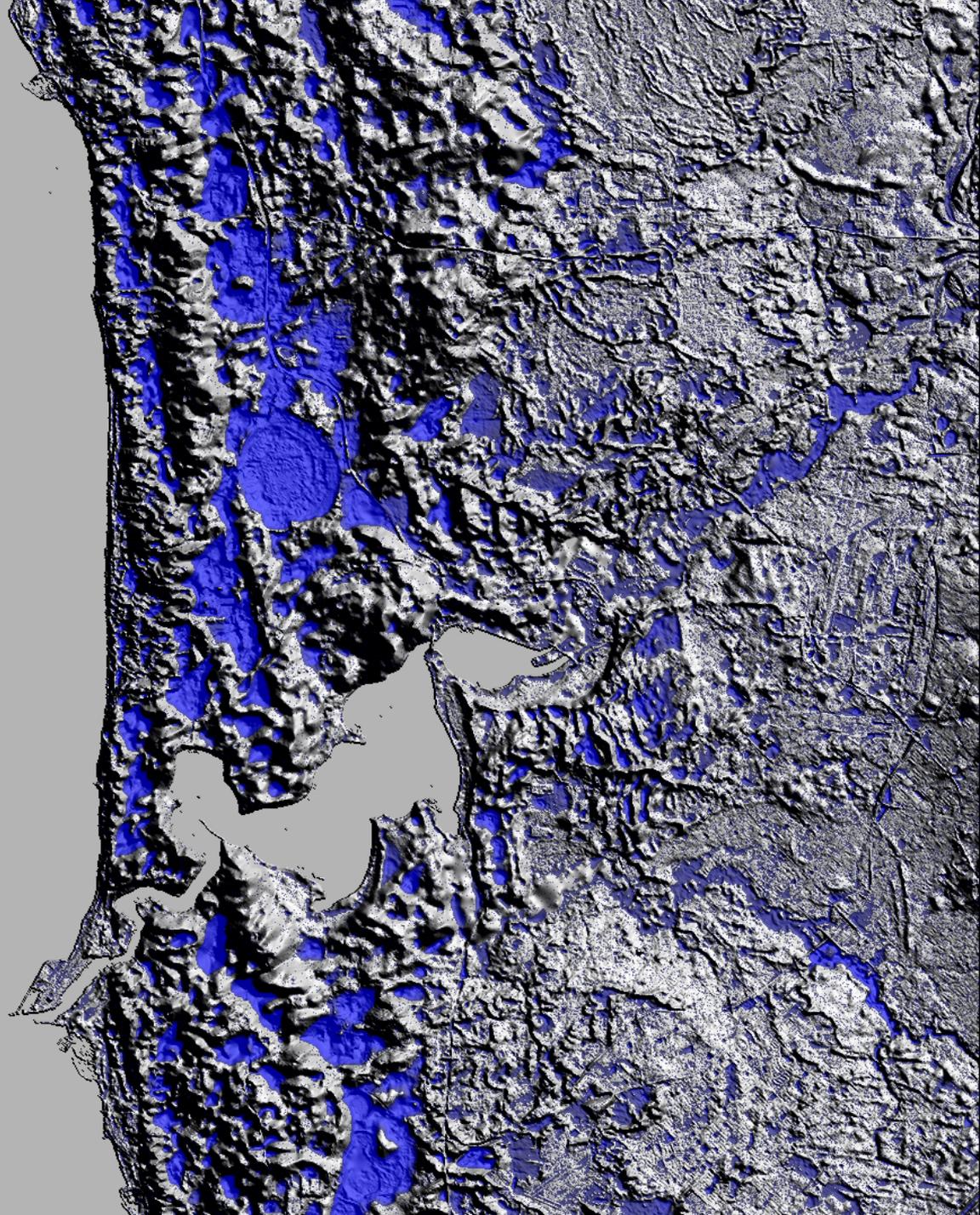
This is evidence that the soils are able to accommodate even the highest intensity rainfall without forming drainages

Source: CSIRO (2009) SWWA Sustainable Yields report



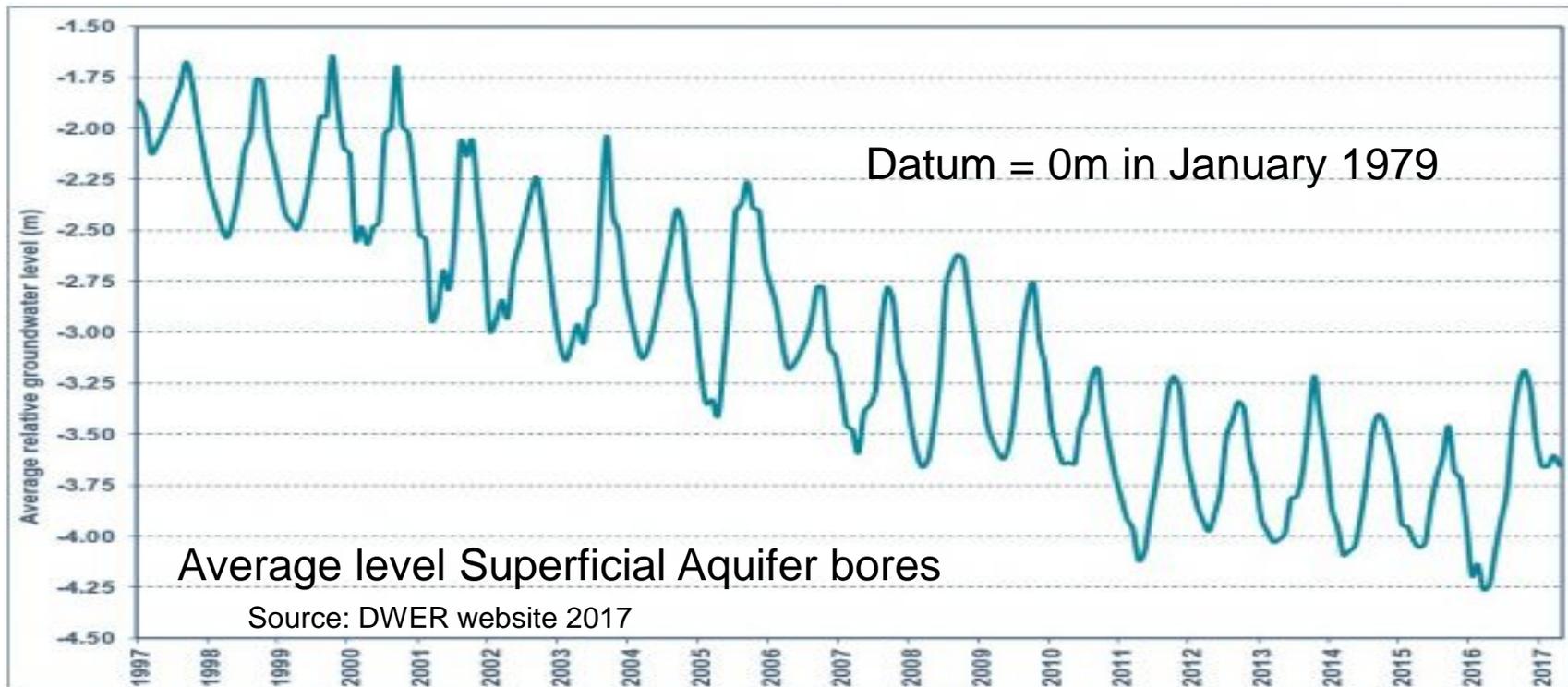
The blue areas are mainly closed depressions. The image shows how full they need to become before they discharge into another depression (unlikely in most cases)

Source: McFarlane, D.J. and Caccetta, P.A (2017). Indirect recharge to the Superficial Aquifer in the area underlain by the Kings Park Formation. Report to the Department of Water and Environmental Regulation from CSIRO, Floreat Laboratories, Australia



Groundwater allocations reduced and compliance enhanced

- Gnamptara Groundwater Areas Allocation Plan (2009) reduced allocations
- Between 2011 and 2014 licence entitlements were reduced by 15% or 42 GL/y
- Water Corporation's entitlements for Gnamptara reduced to 110 GL/y
- Metering progressively required for smaller allocations
- Sprinkler and winter watering restrictions
- Corridor water supply strategies being developed that include MAR
- Further reductions are planned in the next Gnamptara Allocation Plan (2018)



The values that the shallow groundwater supports are:

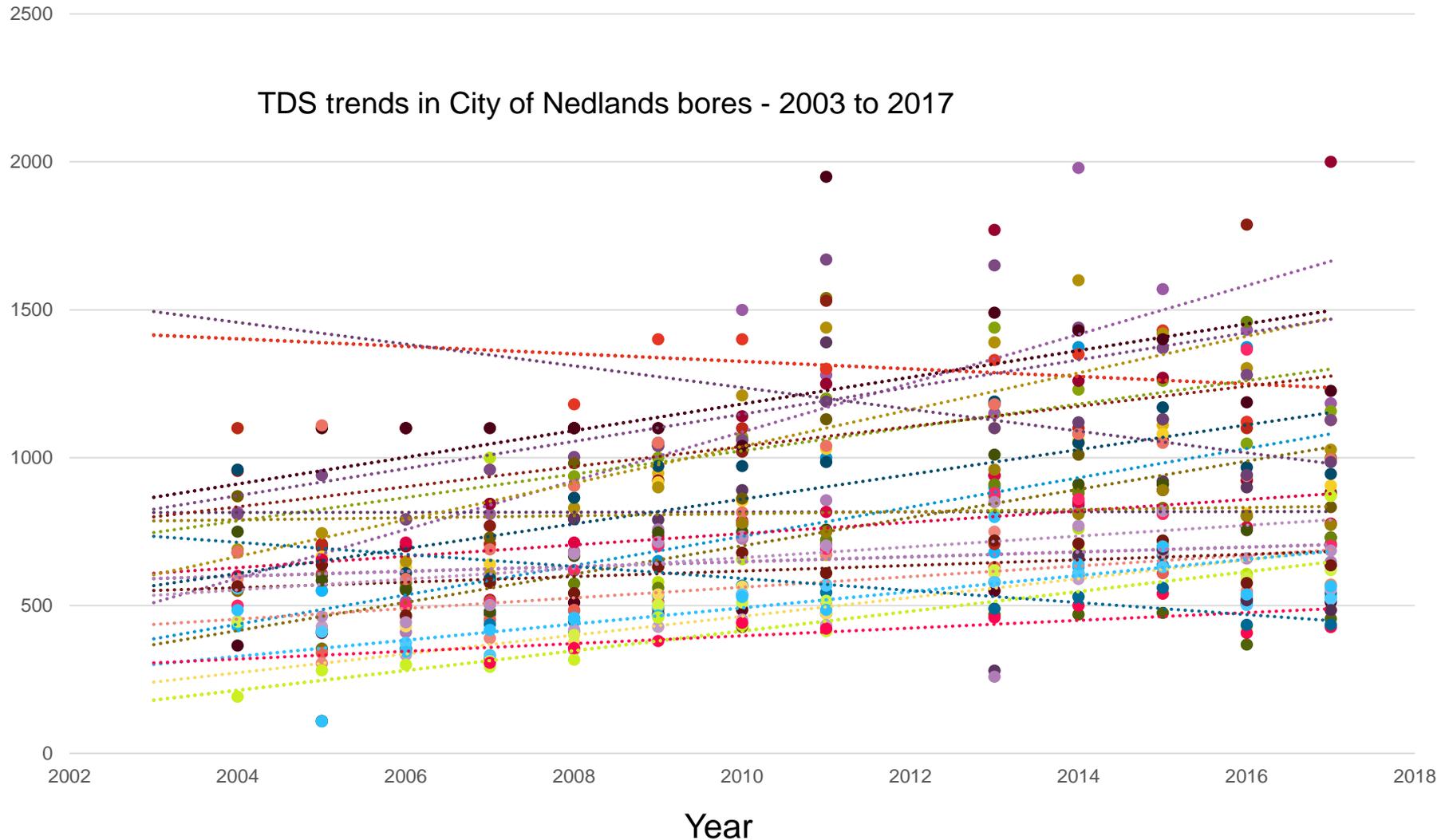
1. 13% of our drinking water supply, now mostly from under urban areas
2. About 176,000 unlicensed backyard bores irrigates one-in-four private gardens. Bores reduce the demand for drinking water
3. Irrigation of local government parks, golf clubs, school ovals
4. Peri-urban horticulture – fresh fruit and vegetable
5. Industrial use – e.g. 70% of water used in the Kwinana industrial area
6. Most urban wetlands rely on groundwater. Their values include
 - Increase in surrounding land values by over \$4 billion
 - Amenity for people outside this 5 to 10 km proximity zone
 - Habitat for waterbirds, estuarine birds, tortoises etc
 - Educational and other benefits
7. Cheap disposal of stormwater; removal of salts; preventing salt water intrusion in ocean and river; stops wetlands from releasing nutrients, acidity and heavy metals including arsenic
8. Irrigation and lakes help reduce the ‘heat island effect’
9. Cooling or heating of buildings and super computers

Groundwater salinities appear to be gradually increasing

Data source: City of Nedlands (2017)



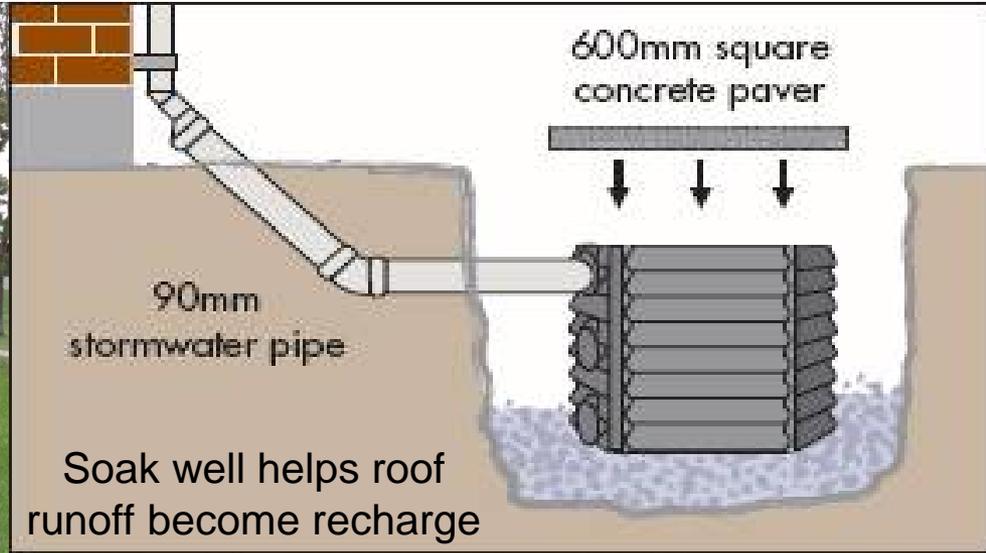
TDS (mg/L)



“

Stormwater as a source of MAR water

Stormwater is important for recharge



Herdsman to
Floreat main drain

Floreat Beach main drain

Absorption basin for road runoff

380⁰⁰⁰E 385⁰⁰⁰E 390⁰⁰⁰E 395⁰⁰⁰E 400⁰⁰⁰E 405⁰⁰⁰E

0⁰⁰⁰N

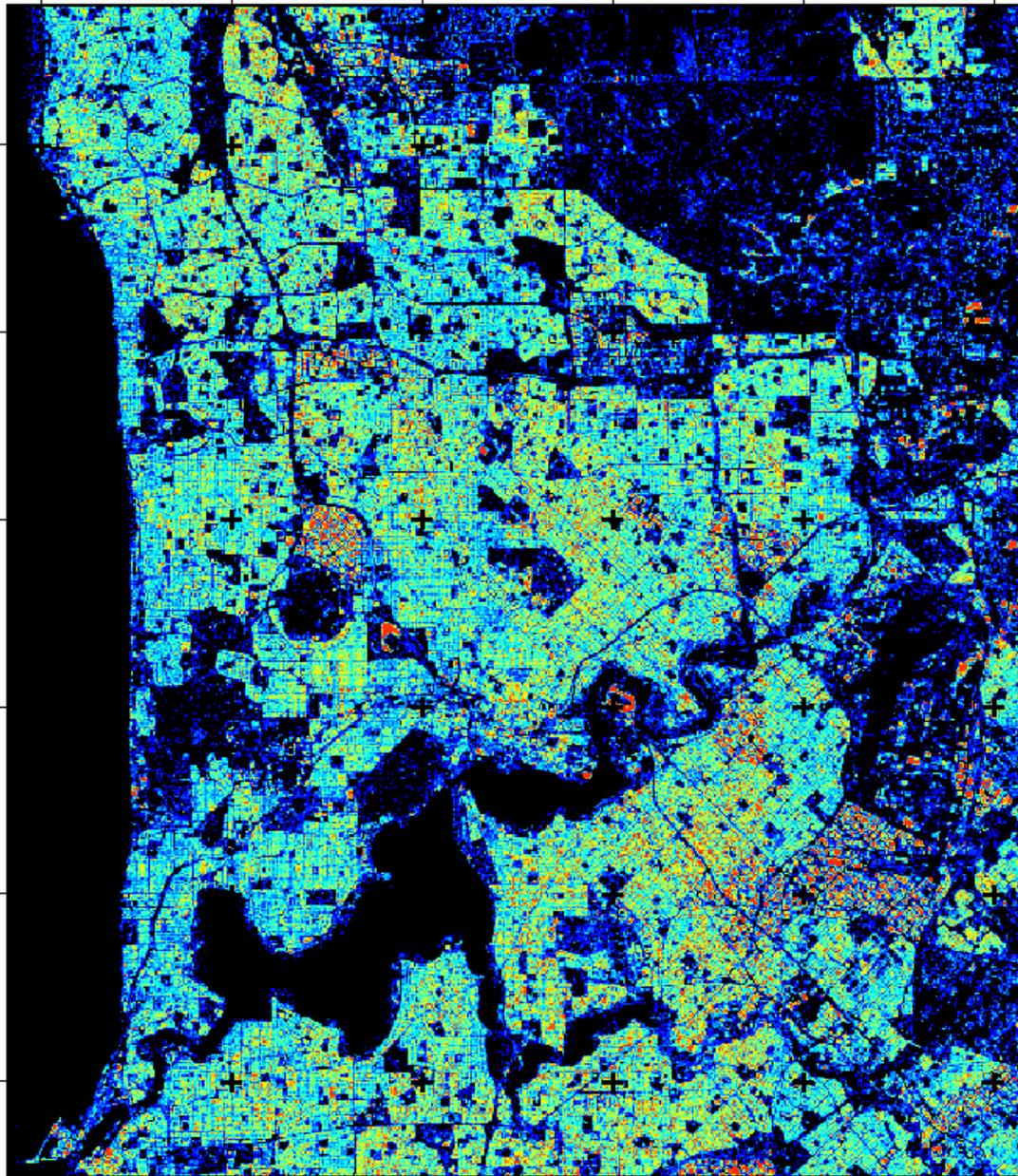
5⁰⁰⁰N

0⁰⁰⁰N

5⁰⁰⁰N

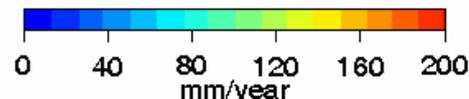
0⁰⁰⁰N

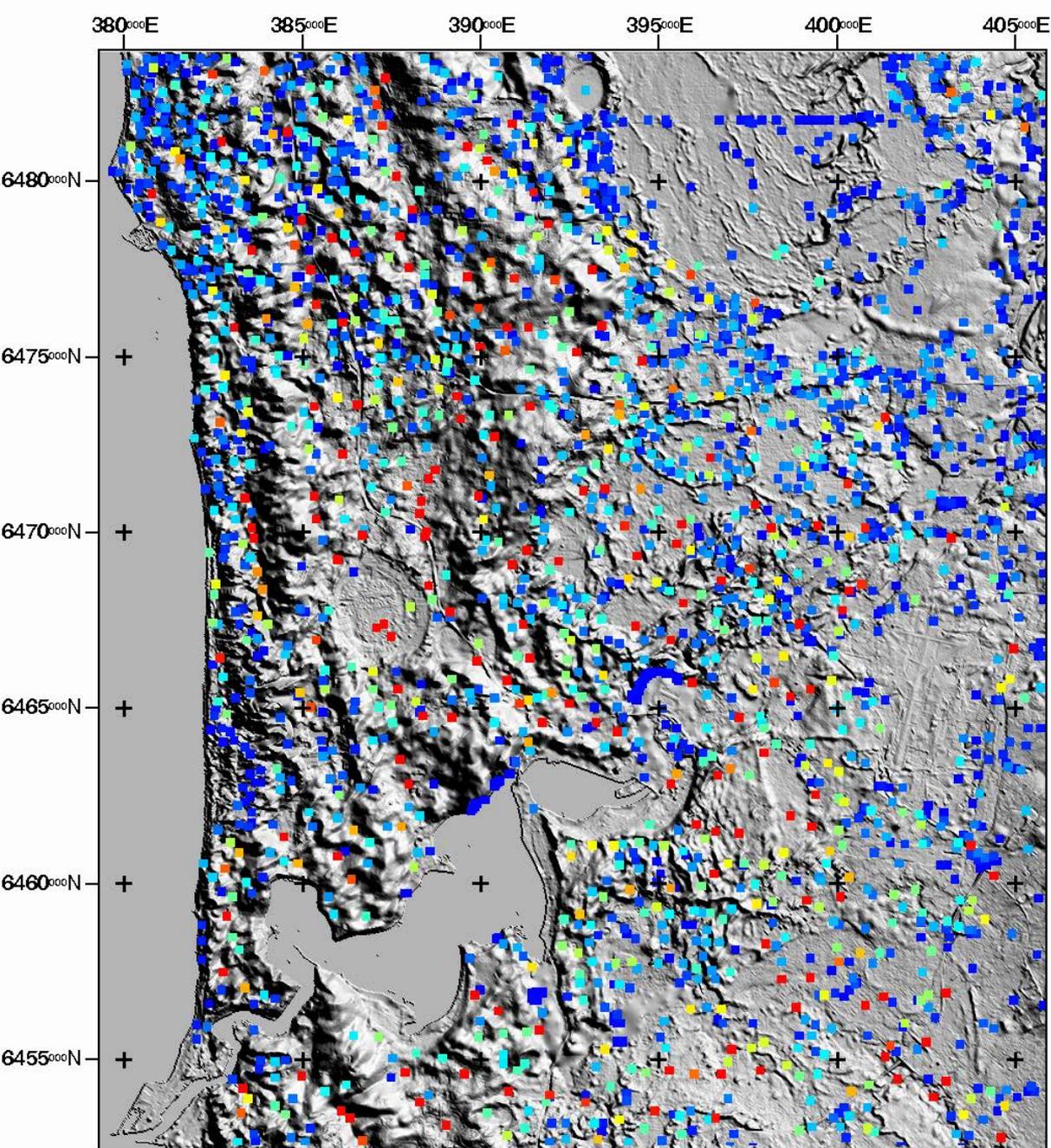
5⁰⁰⁰N



Estimation of recharge from roofs on a 50x50m grid basis

Source: McFarlane, D.J. and Caccetta, P.A (2017). Indirect recharge to the Superficial Aquifer in the area underlain by the Kings Park Formation. Report to the Department of Water and Environmental Regulation from CSIRO, Floreat Laboratories, Australia





Estimation of recharge from roads on a 50x50m grid basis

Source: McFarlane, D.J. and Caccetta, P.A. (2017). Indirect recharge to the Superficial Aquifer in the area underlain by the Kings Park Formation. Report to the Department of Water and Environmental Regulation from CSIRO, Floreat Laboratories, Australia

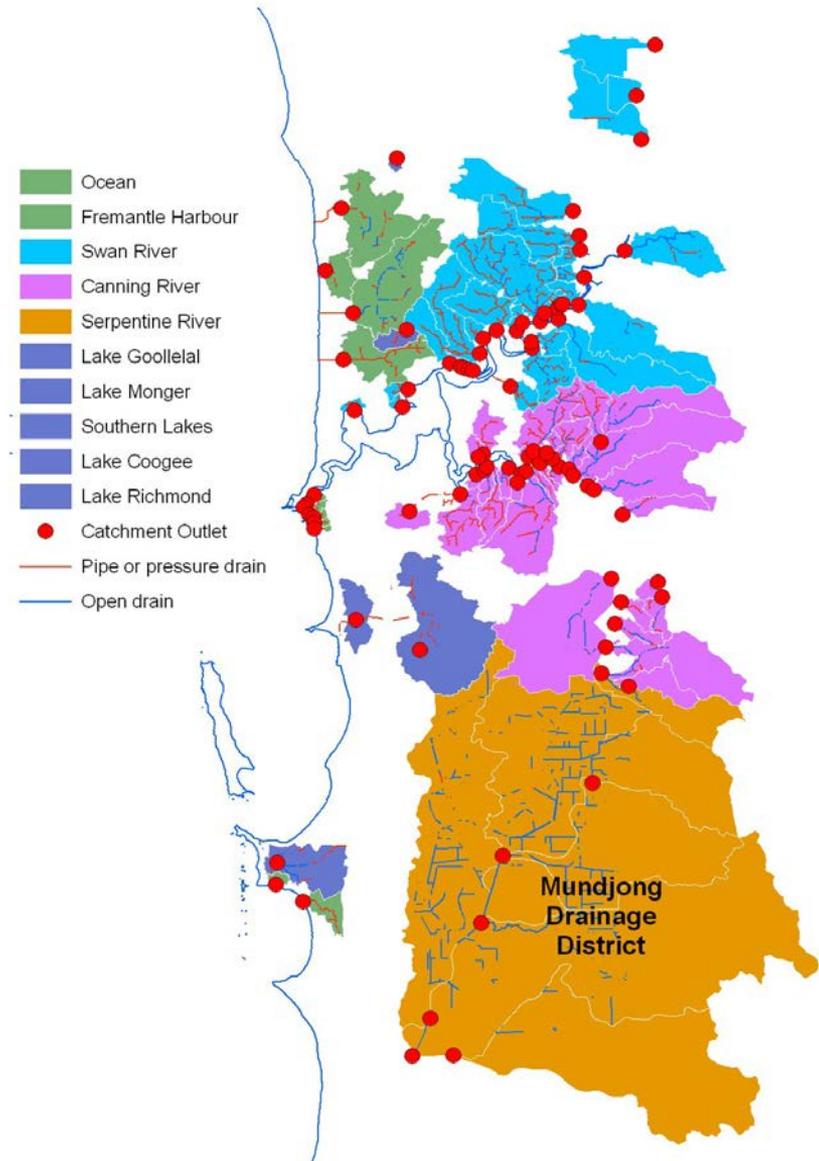
Estimation of flows from main drains

- Outlets

– Swan – Canning	80 GL/yr
– Ocean	18 GL/yr
– <u>Peel</u>	<u>21 GL/yr</u>
TOTAL	~120 GL/yr

- Rainfall runoff (~ 40%)
- Groundwater discharge (~ 60%)
- Need both a source and a sink
- Increasing interest by coastal shires in diversion to the aquifer
- **Volumes are decreasing rapidly**

Sources: GDH (2008) Potential Use of Stormwater in the Perth Region Quantity and Storage Assessment Report for DoW; and Geoff Hughes (Water Corporation, 2007)



Stormwater quality

Contaminants in stormwater discharge and associated sediments at Perth's Marine Beaches (DoW 2007)

- Main contaminants are microbes and heavy metals (Al, Cu, Fe, Pb)
- Nutrient concentrations were generally low with a few exceptions

Non-nutrient contaminants in the Swan Canning River System (SRT 2009)

- The levels in water and sediments were typical for urbanised catchments
- Organochlorine pesticides (eg dieldrin) and metals are the main issues
- Polycyclic aromatic hydrocarbons, herbicides, petroleum hydrocarbons and anionic surfactants may also be high

In-stream processes also affects main drain water quality (Donn and Barron 2012)

Impacts of stormwater MAR on groundwater quality

- McFarlane (1984) and Appleyard (1993) reported reduced salinity and increased oxygenation in groundwater near infiltration basins. When oxygen levels are low in wetlands before stormwater enters, iron can be leached from unsaturated yellow sands resulting in intense iron staining when used for irrigation
- Appleyard found no fecal coliforms, streptococci or *Salmonella* organisms in the groundwater near infiltration basins
- Current MSc on Perry Lakes which is dominated by stormwater inflows

Herdsman to Floreat main drain diversion to bush on Wembley Golf Course



Dive structure to divert water under Empire Avenue into a low point (5.44m AHD) in flooded gums bush on golf course

Cost ca. \$220K.

Flow = 9.8 GL/y in 1993-1999

Source: GHD (2010). Town of Cambridge Report on Herdsman Main Drain Diversion Technical Analysis

Main drain diversion 2011 option



Scenario 2 5,000m² basin infiltrating 1.7 GL/y
Capital cost \$648K; operating \$117K/y

Scenario 4 10,000m² basin infiltrating 2.1 GL/y
Capital cost \$966K; operating \$124K/y

Scenario 6 15,000m² basin infiltrating 2.5 GL/y
Capital cost \$1,287K; operating \$131K/y

Town of Cambridge uses 1.8 GL/y from the
Superficial Aquifer for irrigation

Source: GHD (2011) Town of Cambridge. Report for
Herdsman Main Drain Diversion and Infiltration Options
Assessment

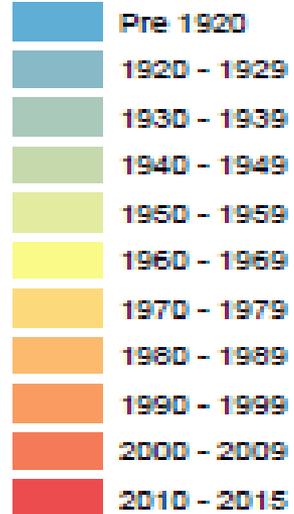
“

Treated wastewater as a source of MAR water

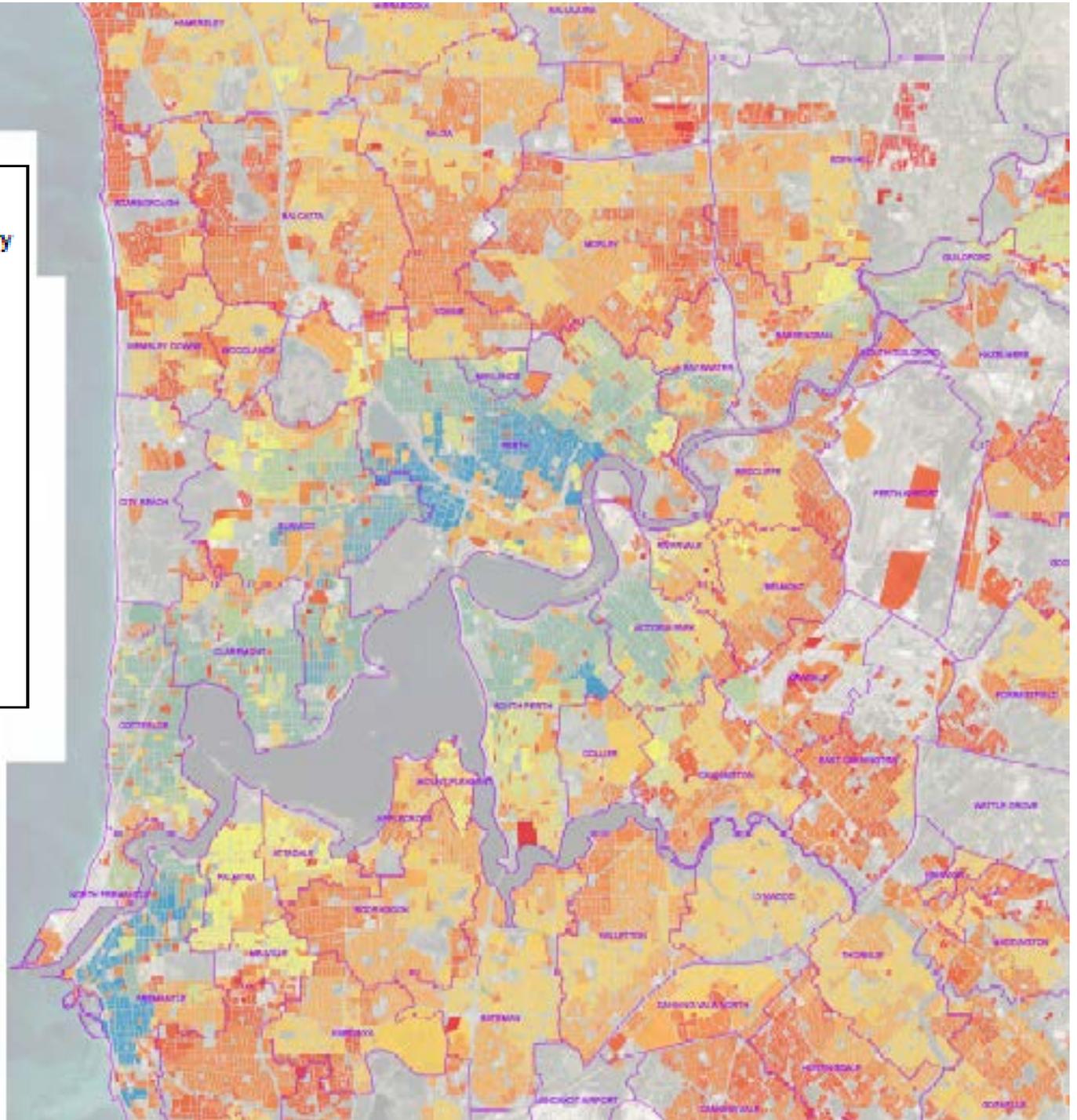
Legend

 Sewer District Boundary

Sewered Area Per Decade



It was not that long ago septic tanks provided water and nutrients to the groundwater under Perth



Wastewater discharge to the ocean and aquifer

Source: Water Corporation



Wastewater discharge 2013

Ocean outfalls

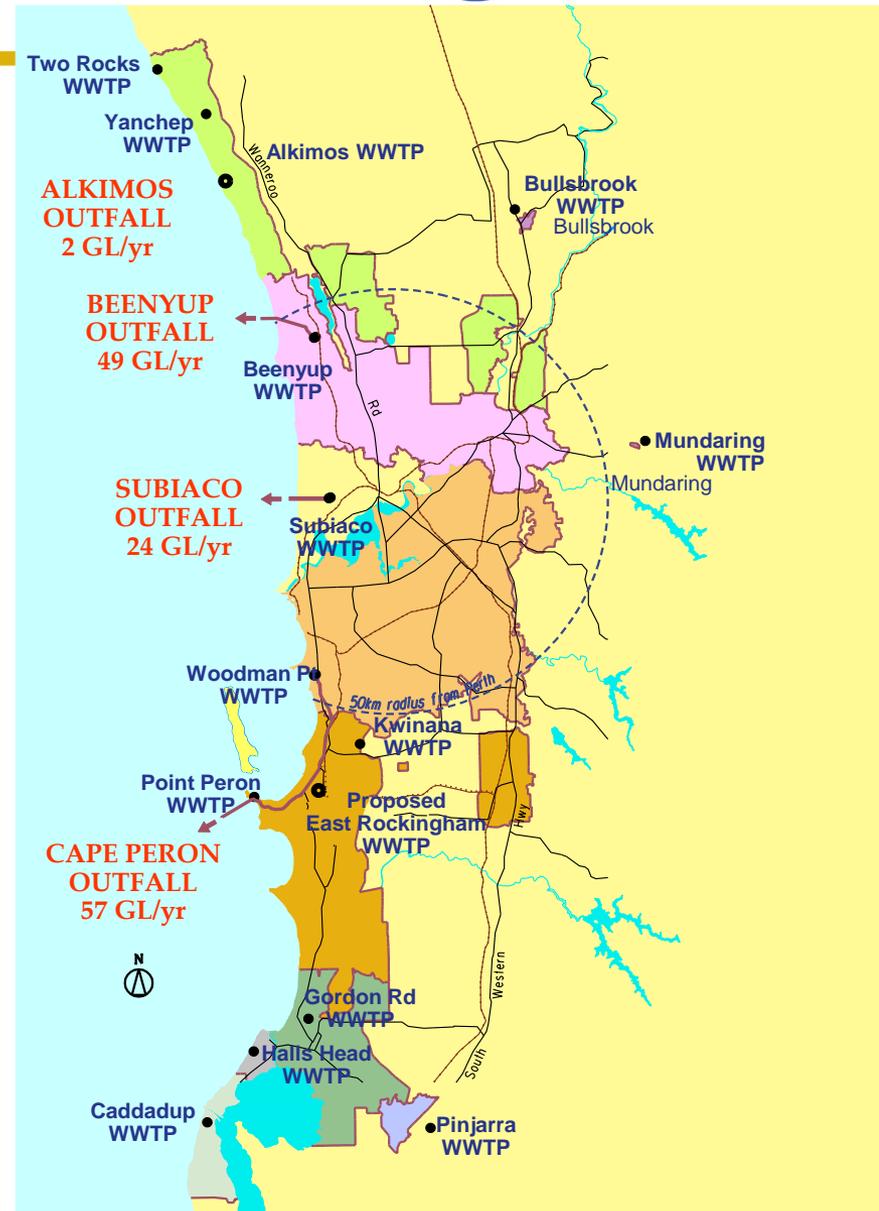
• Alkimos	2
• Beenyup	49
• Subiaco	24
• <u>Cape Peron</u>	<u>57</u>
Total	132 GL/yr

Coastal infiltration sites

• Yancheop	0.23
• Kwinana	1.70
• Gordon Rd	3.45
• Halls Head	0.90
• <u>Caddadup</u>	<u>0.54</u>
Total	6.82 GL/yr

Groundwater replenishment trial

• Beenyup	1.4 GL/y
2017+	ca. 14.0



“

Ability of the Superficial Aquifer to accept MAR water

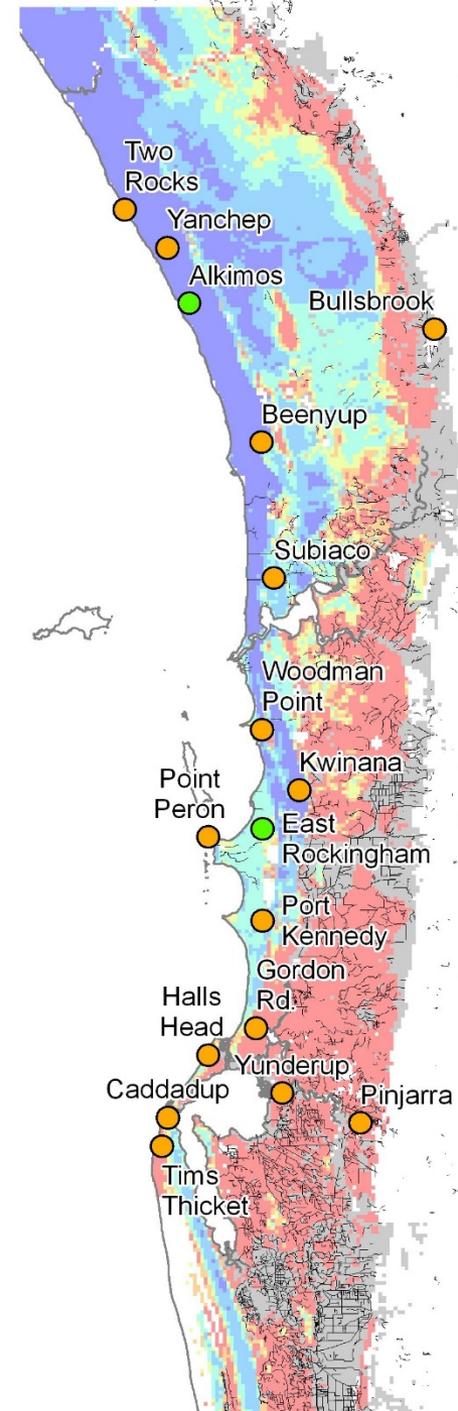
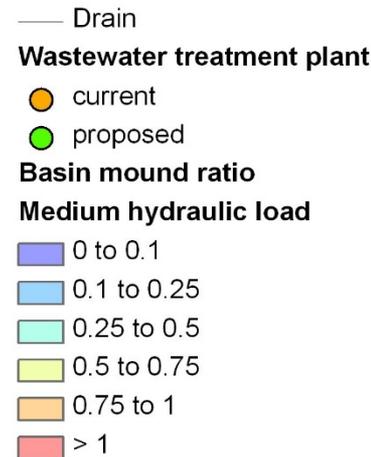
Suitability for MAR Basin infiltrating 5 ML/d

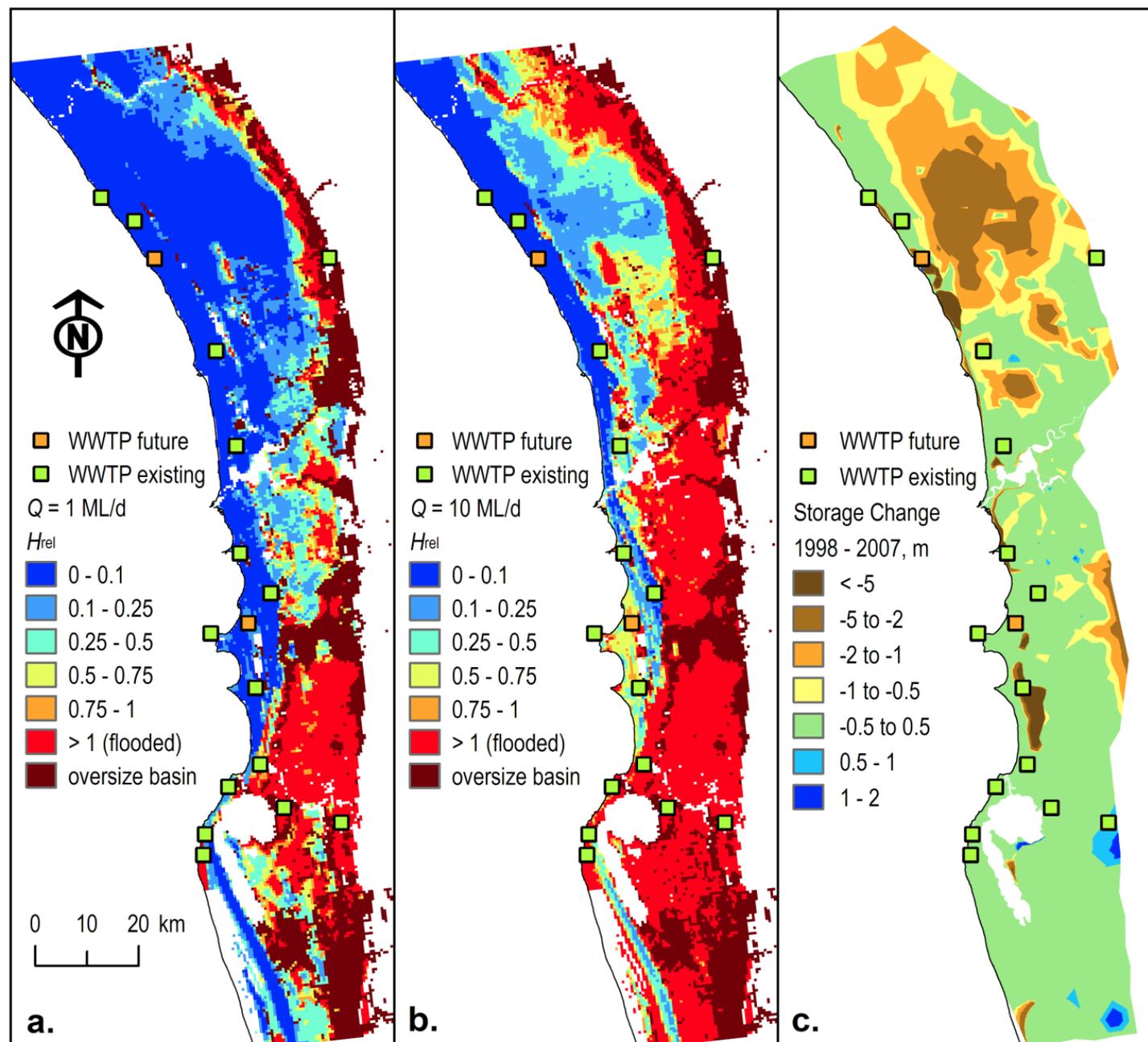
Smith and Pollock 2010

- Grey – infiltration rates very poor
- Pink – high watertable and low transmissivity means that the infiltrated water may reach the surface
- Light blue – suitable; may enhance wetlands by raising groundwater levels
- Dark blue – suitable; no impact on wetlands; may help prevent salt water intrusion



20 km

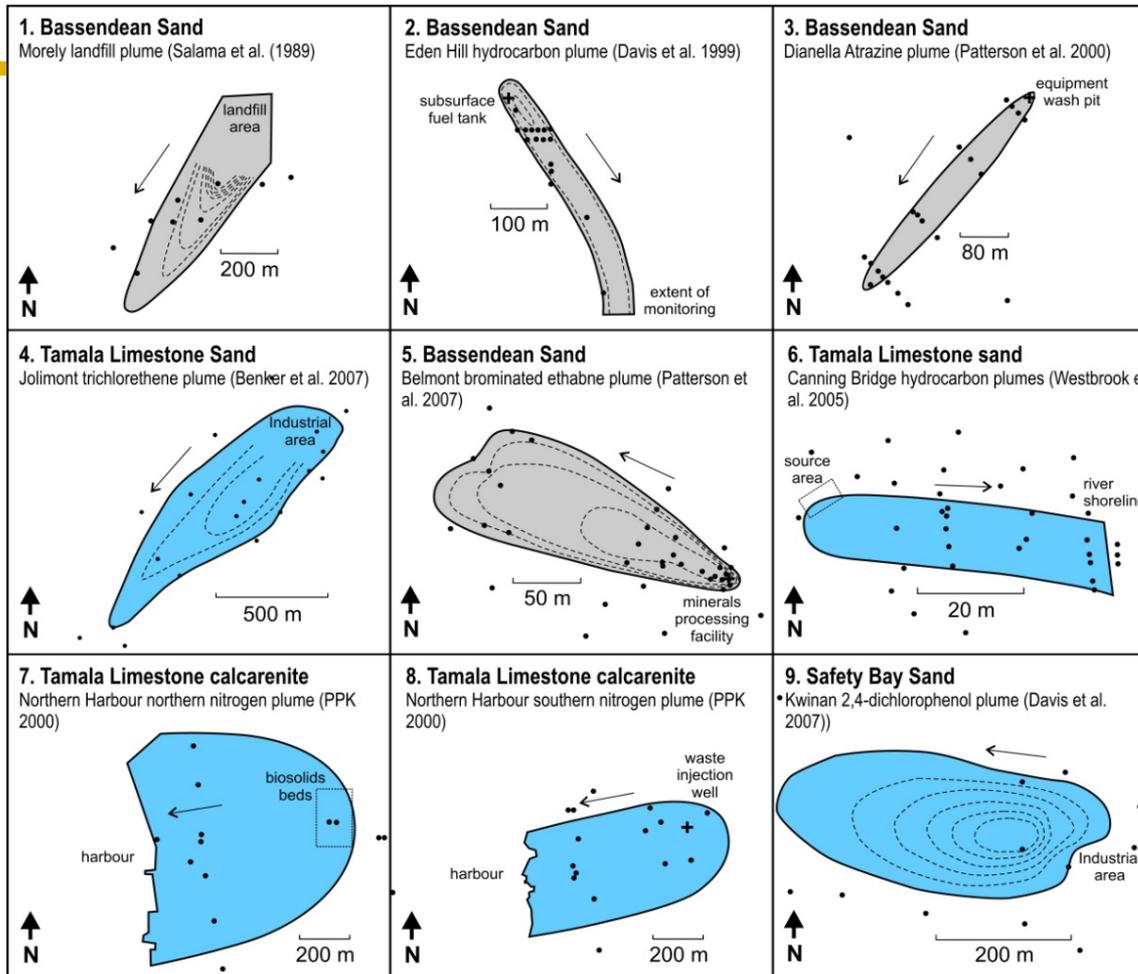




Relative watertable rise
beneath the centre of a
square recharge basin
at 30 days
continuous operation
calculated in 21,335
contiguous cells using
Glover's (1961) solution

- (a) Small (1 ML/d)
hydraulic load.
- (b) Large (10 ML/d)
hydraulic load.
- (c) Calculated 10-year
change of aquifer
storage expressed as
change of fresh water
thickness in the
superficial aquifer
between 1998 and 2007
(from: Smith and
Pollock 2011)

Regular plume geometries and other evidence suggests the risk of conduit flow in Tamala Limestone is low



LEGEND

-  Source / source area
-  Monitoring location
-  Inferred plume extent and concentration contour
-  Watertable slope

SITE AQUIFER CHARACTERISTICS

1. Fine to medium sand ~70 m thick over clay unconformity
2. Fine to medium sand 7–12 m thick over clay
3. Fine to medium sand ~50 m thick over Cretaceous unconformity
4. Predominantly medium grained quartz sand
5. Stratified sand with thin clay lenses ~20 m thick over <1 m thick clay, underlain by ~30 m of coarse sand
6. Medium to coarse sand ~8 m thick over clay
7. Fine to coarse grained calcarenite, variably lithified 45–50 m thick
8. As above
9. Fine to medium sand 10–18 m thick over 1–2 m thick silty aquitard, underlain by 15–20 m of calcarenite

- Suggestive of larger lateral dispersion in Tamala Limestone
- 93% of bores with no mention of secondary porosity in Tamala Limestone
- Tamala Limestone in the Perth region contains a predominantly diffuse-flow aquifer rather than one dominated by conduits and cavern flow; with the exception of cave areas
- Dual porosity due to partial dissolution

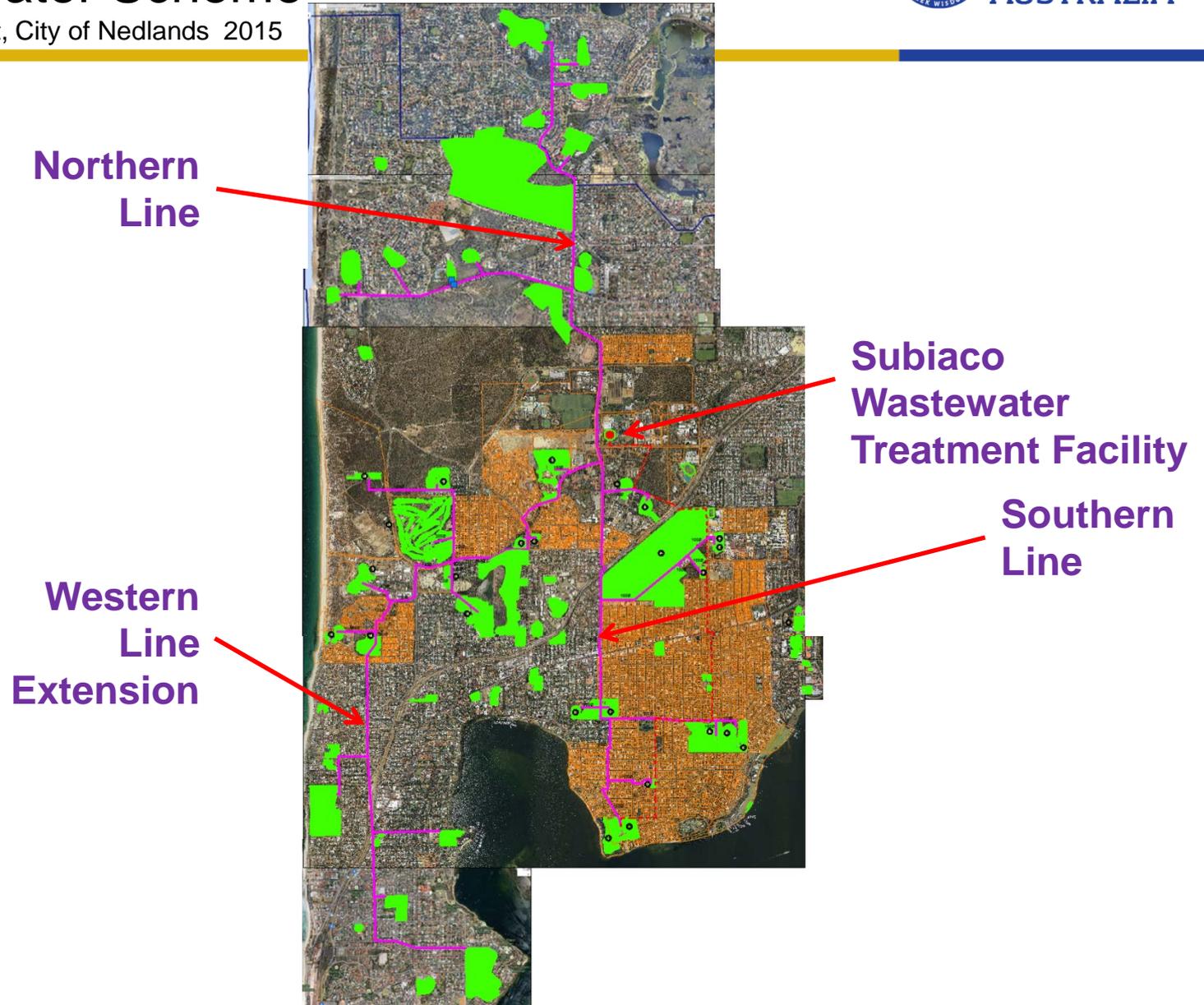
Source: Is the Tamala Limestone aquifer safe for managed aquifer recharge? Tony Smith, Sylvain Massuel and Daniel Pollock (IAH Conference, 2013)

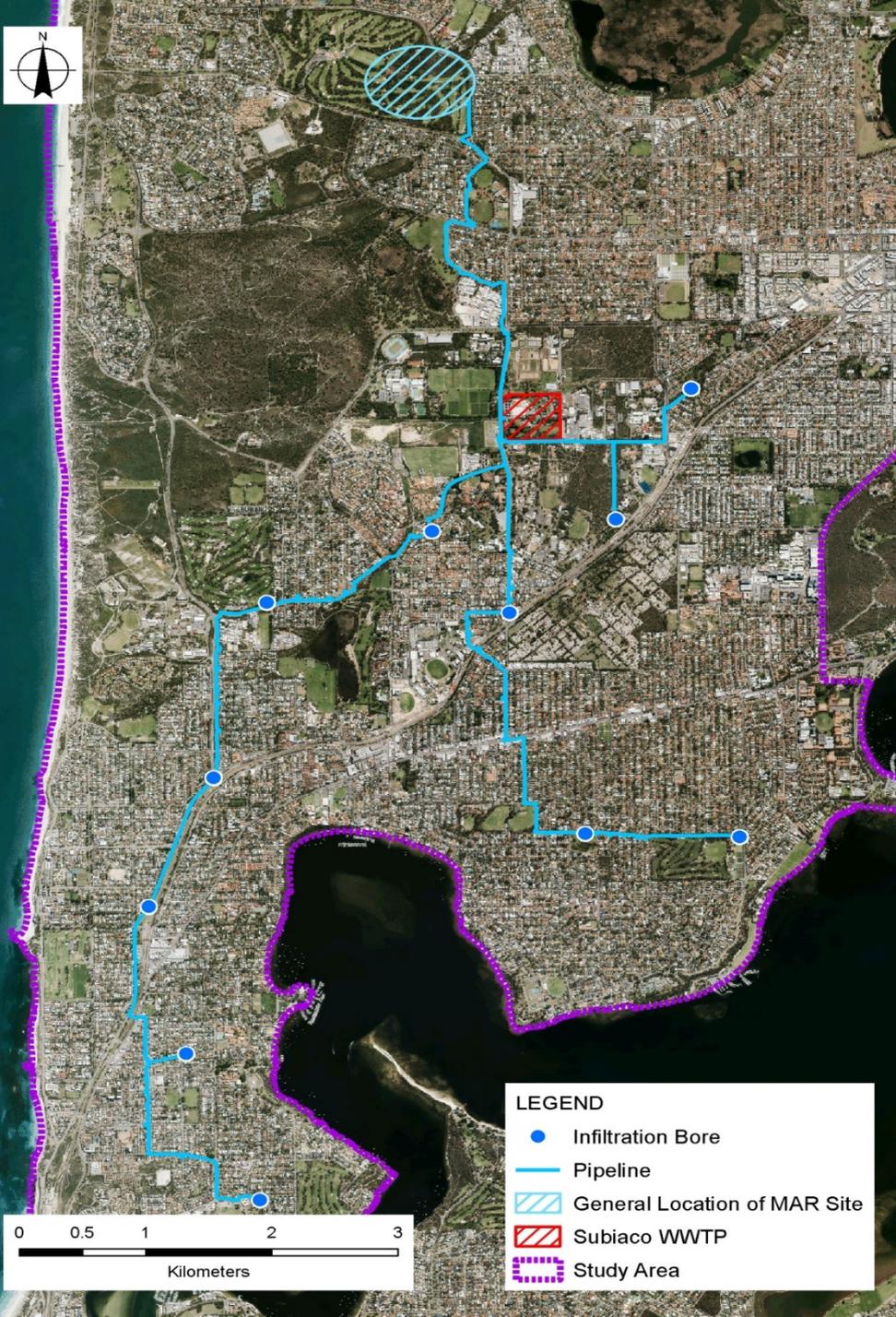
“

Advantages of MAR over surface engineering options

Western Suburbs Recycled Water Scheme

Source: Mark Goodlet, City of Nedlands 2015





One option for taking water from the Subiaco WWTP to infiltrate near public open space irrigation areas

Source: Western Suburbs Managed Aquifer Recharge Pre-Feasibility Study. GHD report to Department of Water (2016)

Managed aquifer recharge has benefits over direct piping of treated wastewater

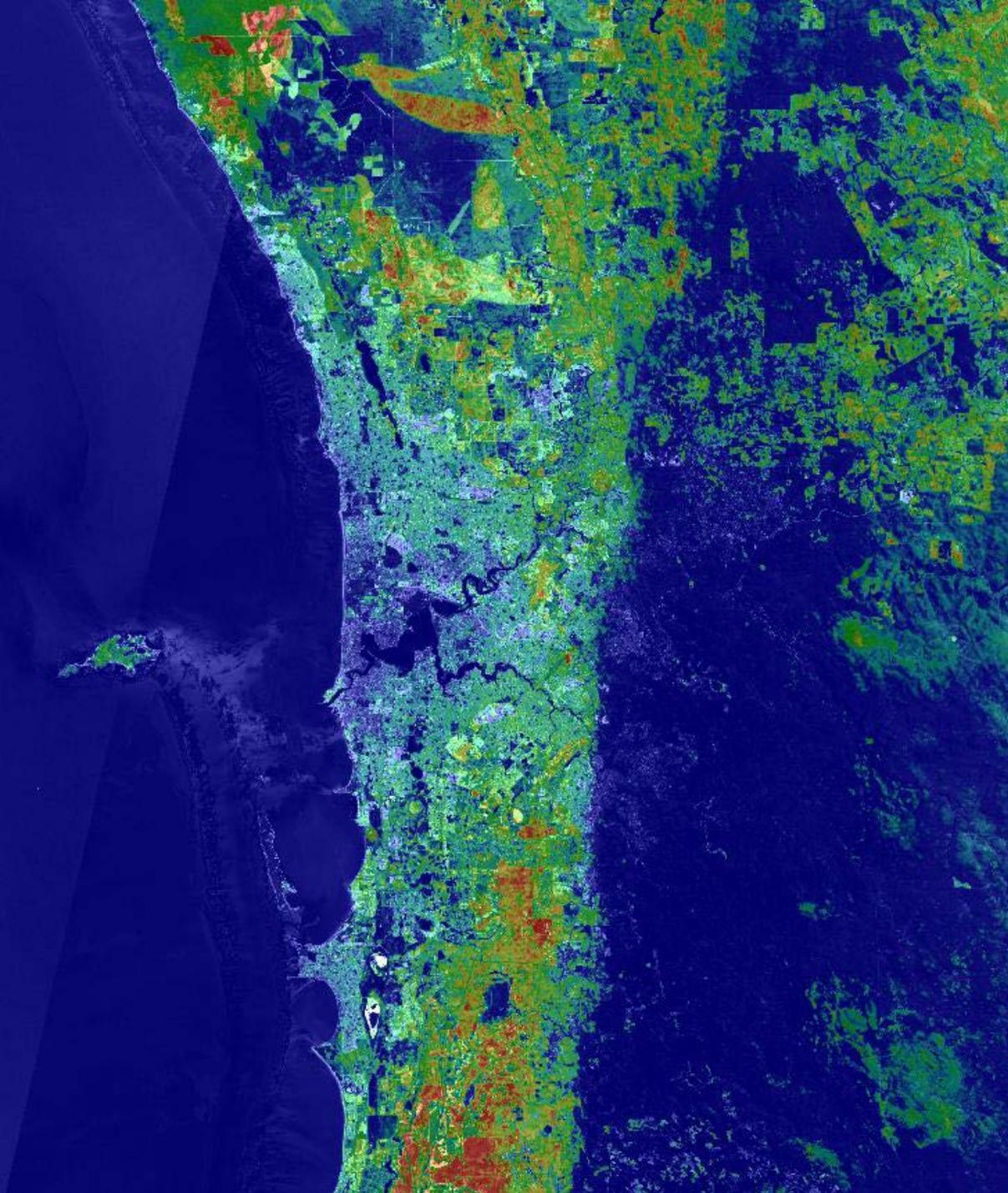


- It raises groundwater levels benefiting wetlands and private bore users
- It can help manage salt water interfaces around the river and ocean
- Treated wastewater can be added all year round
- There is no need for storage, and less need for treatment than a piped scheme (no chlorination costs)
- Water flows to existing extraction networks reducing costs
- The distribution network can be simple

Advantages of a piped scheme to POS are:

- More control over water quality (chlorination)
- Directly targets individual reserves
- May have more immediate community acceptance

Parties are evaluating both options



Perth urban heat island at 0930 am over summer

The large-block +
private-bore 'garden
suburbs' around the
estuary appear cooler

Source: Devereux, D and Caccetta, P (2017).
Estimation of Land Surface Temperature and
Urban Heat Island effect for Australian urban
centres. Report EP173542 Horticulture
Innovation Australia (HIA) *Where Should All
The Trees Go?* Project Version 1

Conclusions 1

- Perth-Peel's climate, soils and aquifers are (often) ideally suited to MAR
- Asking for more groundwater ended in the 1990s
- Entitlements have decreased and will decrease further without MAR
- The values the Superficial Aquifer support are being lost and we need to be prepared to pay more for non-potable water
- There is no reason why Perth – Pell shouldn't remain green and cool
- Road runoff is now mainly diverted to the aquifer (some coastal and riverine LGAs are still to do this)
- Main drains need to be diverted where feasible to add recharge and clean up the beaches / foreshores; but this won't be enough to offset losses

Conclusions 2

- Treated wastewater may be contested – Groundwater Replenishment for potable use versus MAR for non-potable uses
- Ocean discharge of treated wastewater has increases by 2-3% per annum despite our attempts to meet reuse targets since 2003
- Our biggest needs are:
 - getting community understanding of the values that are being lost as groundwater levels decline;
 - getting the community comfortable with their shallow aquifer accepting wastewater streams
 - getting government regulators to accept the safety of adding treated wastewater to the aquifer.
 - assessing long-term treated wastewater disposal sites at 33 WWTPs is helping
 - we will see several of these sites on our field trip

Thank you



Dr Don McFarlane

Adjunct Professor
School of Agriculture and Environment
University of Western Australia

Mobile: 0407 476 026

Email: don.mcfarlane@outlook.au

Photo Source: Department of Water,
Gnangara Sustainability Strategy

Is MAR an Option?

FEASIBILITY ASSESSMENT USING AUSTRALIAN MAR
GUIDELINES

Regulatory Environment

ENGAGE REGULATORS EARLY

Regulations in Western Australia

Department of Water and Environmental Regulation (DWER):

- Managed under the *Rights in Water and Irrigation Act 1914 (WA)*:
 - 5C Licence for abstraction SW/GW
 - 26D Licence to construct or alter a bore.
- Operational Policy 1.01 – Managed Aquifer Recharge in Western Australia, 2011
- **Mining** – jointly regulated with ERs under Operating Strategies associated with 5C dewatering licence (as a condition to the licence)
 - Strategic Policy 2.09: Use of mine dewatering surplus
 - Western Australian water in mining guidance, Water licensing delivery series – report 12, 2013



Operational Policy 1.01 – MAR in WA

Regulations in Western Australia (cont.)

Environmental Regulation (-ER) and Environmental Protection Agency (EPA):

- Concerned primarily with potential Contaminated Sites impacted by recharge (ER)
- Modifying lakes or potentially impacting the environment – Environmental Management Plan may be required (EPA)
- **Mining** – reinjection licensed as dewatering discharge under Part V *Environmental Protection Act, 1986* – Category 6: Mine dewatering

Department of Health:

- May require monitoring and compliance in cases using recycled water as a source
- Mosquito and midge control



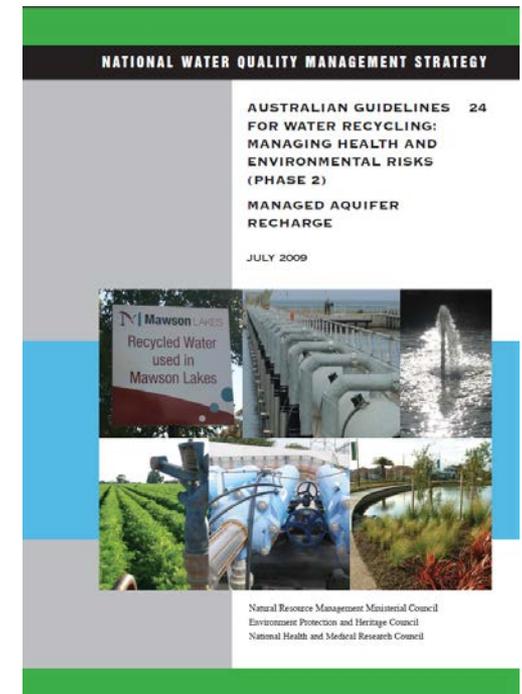
Australian Guidelines for MAR

A systematic, risk-management approach

- *Phase 2 of Australian Guidelines for Water Recycling*, addresses health and environmental risks
- An authoritative reference supporting beneficial and sustainable water recycling
- Provides a scientific basis for implementing decisions

The guidelines aim to:

- Give more certainty to risk assessments used in project approval and speed up the approval process
- Prevent failure of managed aquifer recharge projects
- Uphold the confidence of investors and the public in future innovations

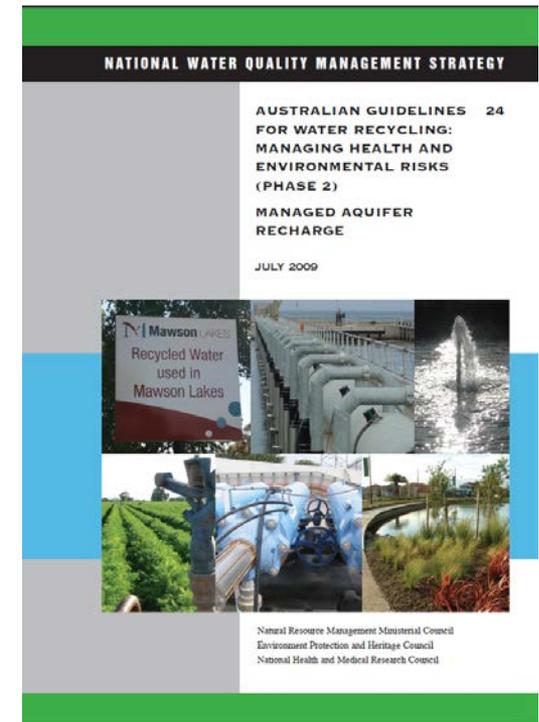


Australian MAR Guidelines (2009)

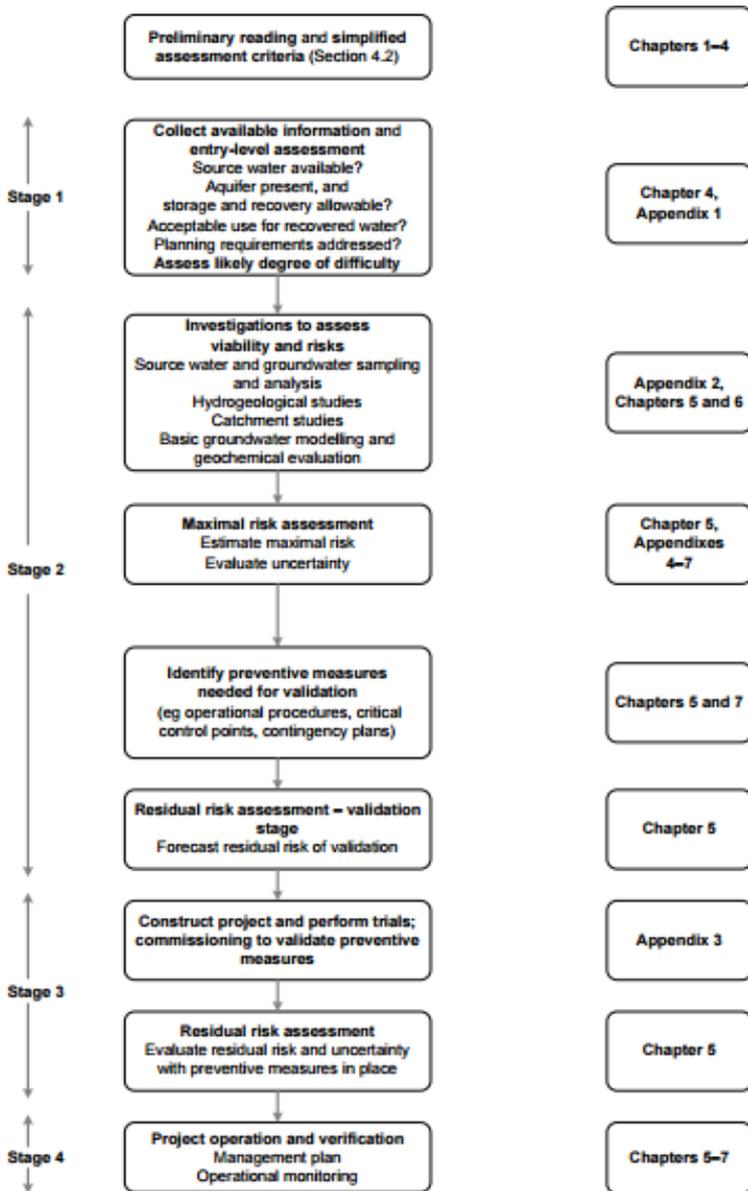
Australian Guidelines for MAR

Proponents, regulators and consultants can use the guidelines to:

- Gain an early understanding of the extent of work needed for a project's success
- Provide a framework for risk assessment and risk management
- Focus time and resources where needed most
- Help proponents discard projects that will not meet objectives at the earliest possible stage
- Assist efficient assessment by regulators and other stakeholders
- Facilitates commissioning trials to validate proposed management controls, encouraging innovation
- Inform decision making, so that decisions are defensible and consistent
- Ensure rational and adaptable monitoring requirements are adopted



Australian MAR Guidelines (2009)



Staged Approach to Development and Risk Assessment

- Systematic process for assessment of feasibility of proposed schemes
- Degree of difficulty assessment useful in setting proportionate expectations
- Clearly identifies data gaps and sets out next steps to obtain required information
- Structured assessment of maximum risk and provision of preventative measures to mitigate those risks
- Provides a defensible position for the allocation of financial and human resources (i.e. towards mitigating the highest risks identified)
- Monitoring to verify preventative measures are effective

Fig. 1.3 How to use MAR guidelines (Australian MAR Guidelines (2009))

Assessing Feasibility of MAR within the Australian Guidelines Framework



Image from Environment SA website – How to plan, build and operate a MAR scheme

Stormwater capture in the City of Holdfast Bay, South Australia

Stage 1 – Desktop Study

High level viability assessment using available information and data

- Identified need/benefit
- Source water available
- Suitable aquifer present
- Acceptable use for recovered water
- Regulatory approval likely
- Planning requirements identified
- Information gaps?

Assess likely degree of difficulty



Project apparently viable \implies Stage 2 - Investigations

Stage 1 – Hypothetical Case Study

Municipal Water Supply

Need to develop alternative water supplies and desire to further promote water sensitive urban design

Main Drain as a potential source of stormwater or a Wastewater Treatment Plant nearby

Superficial, Mirrabooka, Leederville aquifers

Fit for purpose, irrigation or third-pipe water supply

Regulatory approval likely if it fits with DWER's stated position on MAR:

- *The Department of Water supports managed aquifer recharge (MAR) activities that have environmental, social or economic benefits and maximise the use of the state's water resources. The department will approve MAR schemes, provided that recharge and recovery operations will not adversely affect the groundwater system, the environment, existing groundwater users (e.g. through changes in water quality or quantity) or aquifer integrity.*

Entry-level Viability Assessment

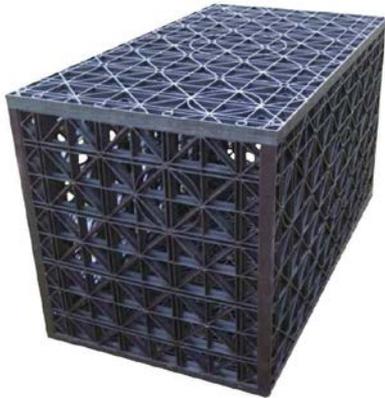
For our hypothetical case study –

Attribute	Fulfilled	Comment
1. Intended water use		
Is there an ongoing demand or clearly defined environmental benefit?	Yes	If not, MAR not recommended
2. Available source		
Adequate source of suitable quality water available?	Maybe	MAR not recommended if the required volume or water quality will adversely impact existing users/environment
3. Hydrogeological assessment		
Is there at least one aquifer capable of storing additional water?	Yes	MAR will only work where hydrogeological conditions are favourable – generally a high yielding aquifer.
4. Space		
Is there sufficient land available for water catchment and treatment?	Yes	Area required depends on system proposed.
5. Technical Capacity		
Are the technical skills and resources available to design, construct and operate a MAR scheme?	Maybe	Often overlooked - requirements will depend on degree of difficulty

Australian MAR Guidelines – Table 4.3

Degree of Difficulty Assessment

Easy to implement



Few resources
Low level technical expertise



Difficult to implement



Many resources
High level technical expertise

Degree of Difficulty Assessment

For our hypothetical case study –

Information Required	Degree of Difficulty
1. Source-water quality with respect to receiving groundwater	
Generally needs to be of equal or better quality than receiving groundwater Stormwater similar quality – low risk, with verification	Meets water quality requirements – low risk Few data, wide variation, some parameters outside requirements – moderate to high risk: monitoring program may be more rigorous
2. Source-water quality with respect to recovered water end use	
Relying on natural attenuation of hazards in the subsurface? Yes – microbiological hazards. Studies show die off in aquifer systems	Water quality monitoring Stage 2 to assess aquifer reactions, verify assumptions Supporting research may be required
3. Source-water quality with respect to clogging	
Poor quality water or fine-grained aquifer Presence of suspended solids or nutrients (nitrate, organic carbon) >10 mg/L Iron/Oxygen reactions	High risk of clogging and water treatment and/or other engineering solution likely to be required Variable water quality – TSS >10 mg/L on occasion, nutrients and TOC present. Moderate to high risk
4. Groundwater quality with respect to recovered water end use	
Water quality data Suitable quality for end use, or relying in improving groundwater quality? Good quality – low risk	If water meets quality requirements – low risk If not, need to account for recovery efficiency and degree of difficulty increased

Australian MAR Guidelines – Table 4.4

Source-Water Quality

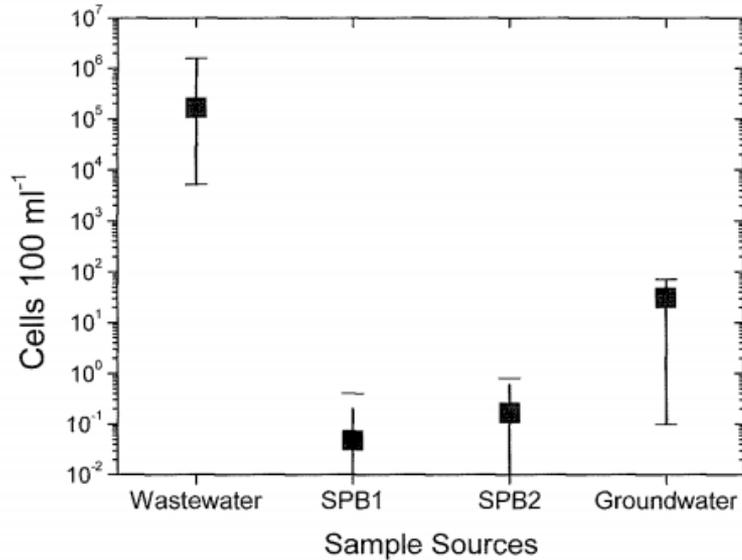


Fig. 1 Maximum, minimum and average *E. coli* numbers detected in water recovered at the Halls Head site (note, 10^{-2} cells 100 ml^{-1} is the detection limit). (Bore SPB1 is located 80 m from the ponds and SPB2 is located 100 m from the ponds).

Attenuation of *E. coli* in Tamala Limestone
(Toze et al, 2004)



Mitigating end-use for recovered recycled water

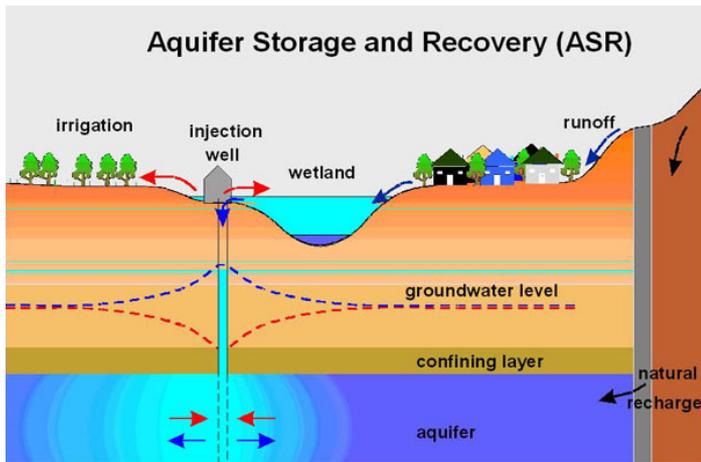
Degree of Difficulty Assessment (cont.)

For our hypothetical case study –

Information Required	Degree of Difficulty
5. Groundwater and drinking water quality	
<p>Environmental values of the aquifer to be defined and maintained, e.g.:</p> <ul style="list-style-type: none">• Raw drinking water• Irrigation• Aquaculture, recreation and livestock• Support aquatic ecosystems with various conservation values	<p>If the aquifer is a source of drinking water supply, or hosts aquatic ecosystems with high conservation or ecological values then the risk of groundwater pollution may be “high” depending on the source water quality.</p> <p>Site specific. Generally drinking water aquifers are protected. Interaction with lakes/wetlands to be assessed.</p>
6. Groundwater salinity and recovery efficiency	
<p>Development of a density-driven freshwater lens above saline groundwater can make recovery of suitable quality water difficult.</p>	<p>If groundwater salinity is >10,000 mg/L and salinity criteria exist for the proposed end-use, there is a high risk of low recovery efficiency.</p> <p>Risk in coastal areas</p>
7. Reactions between source water and aquifer	
<p>Reactions induced in the aquifer through addition of source water may adversely impact water quality, cause clogging, or excessively dissolve the aquifer.</p> <p>Redox status, pH, temperature, nutrients and ionic strength should be assessed.</p>	<p>The greater the contrast between the quality of source and native groundwater the higher the risk of adverse reactions. For high contrast waters, geochemical modelling may be necessary in Stage 2. Assume similar water quality, leached silica sand aquifer – low risk with verification</p>

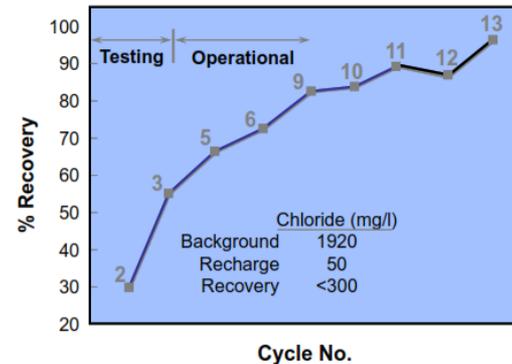
Groundwater salinity and recovery efficiency

Recovery Efficiency: *volume of water recovered each cycle as a percentage of water stored* (Pyne, 2013).



CSIRO, 2000

Percent Recovery by Cycle



Pyne, 2013

Each cycle approximately 40 to 60 MG (150 to 225 MI) stored and recovered

Affected by:

- Aquifer type
- Hydraulic characteristics
- Groundwater salinity
- Amount of water recharged
- Pumping regime

Reaction between source water and aquifer

Metals may be released due to mineral dissolution.

- Probably most common adverse reaction in MAR schemes is mobilisation of As
- Co, Mn, Cd have been released in measurable amounts in Perth Basin schemes, but generally not at levels above drinking water standards

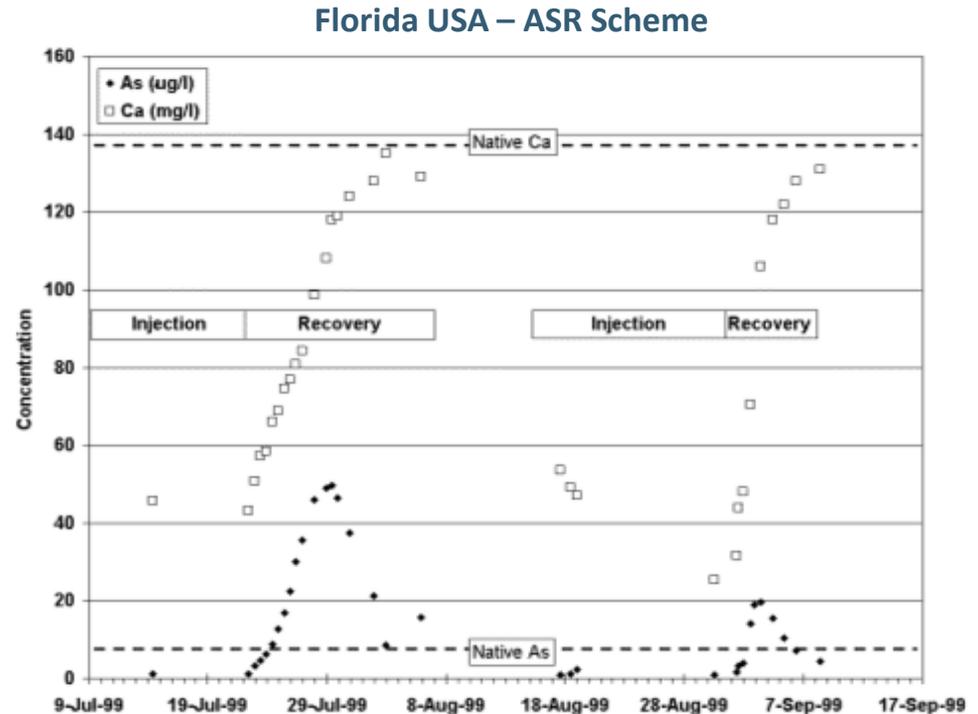


Figure 1. Punta Gorda cycle tests: As and Ca distributions. During recovery, mixing of low-Ca injected waters and higher-Ca native ground water is observed. Arsenic concentrations in recharge and native ground waters are less than 10 µg/l. An As peak (up to 50 µg/l) is observed indicating water-rock interaction.

J.D Arthur et. al, 2002

Degree of Difficulty Assessment (cont.)

For our hypothetical case study –

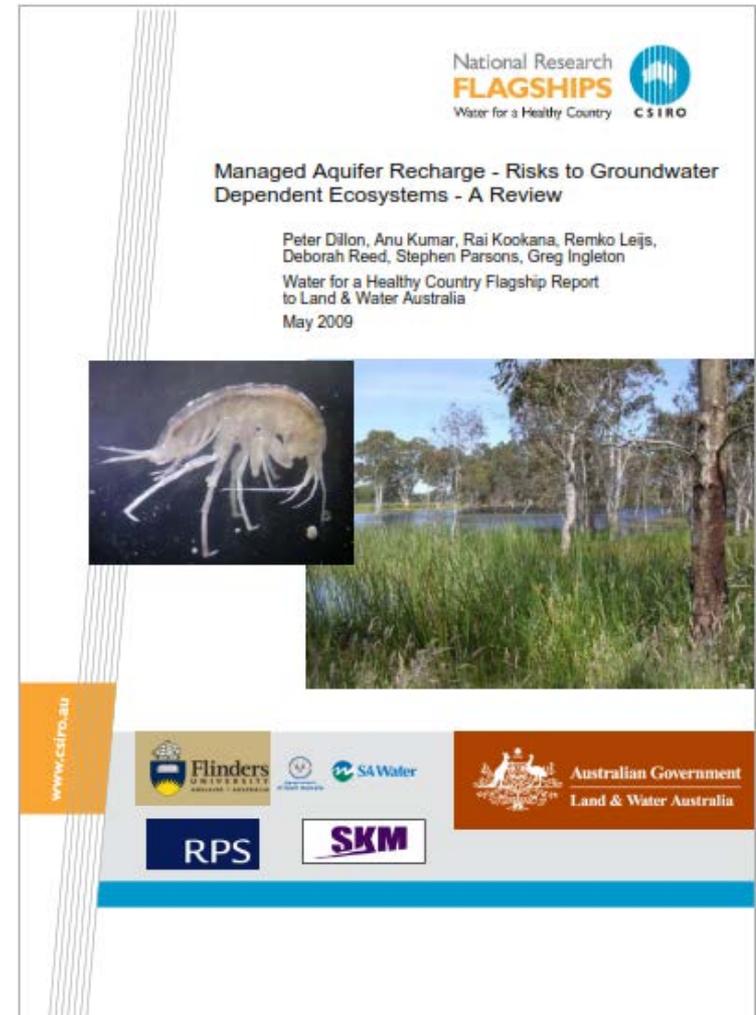
Information Required	Degree of Difficulty
8. Proximity of nearest existing groundwater users, connected ecosystems and property boundaries	
<p>Proximity of nearest groundwater users and connected ecosystems likely to influence the extent of investigations required in Stage 2.</p> <p>Water quality, temperature changes and/or increased pressures may extend beneath neighbouring properties.</p>	<p>If there are other users, connected ecosystems or property boundaries within 100 – 1000 m there is potentially a high risk of impact.</p> <p style="text-align: right;">Site specific</p>
9. Aquifer capacity and impact on groundwater levels	
<p>Groundwater mounding will depend on hydraulic properties of the aquifer, size of recharge area and recharge rate.</p> <p>Magnitude of mounding to be estimated in Stage 2, however excessive mounding can cause:</p> <ul style="list-style-type: none">• Waterlogging• Flooding/damage of infrastructure• Soil salinisation <p>Shallow unconfined aquifers generally unsuitable for large scale recharge</p> <p>Risk of over-pressurising confined aquifers</p>	<p>If the aquifer is unconfined with water table <4 m depth in rural area or <8 m depth in an urban area the risk of water logging is high and investigations will be necessary to decide whether the risk is acceptable.</p> <p>Pressurising artesian aquifers may cause bores to flow, compromise the confining layer.</p> <p style="text-align: right;">Site specific. Urban environment risk to neighbouring properties foundations, infrastructure etc.</p>

Proximity of connected ecosystems

MAR may affect GDEs via:

- Changes in water table elevation
- Changes to piezometric head at springs
- Changes to water quality
- Potential receptors include:
 - Aquatic fauna
 - Algae
 - Wetland vegetation

Rate of change is important

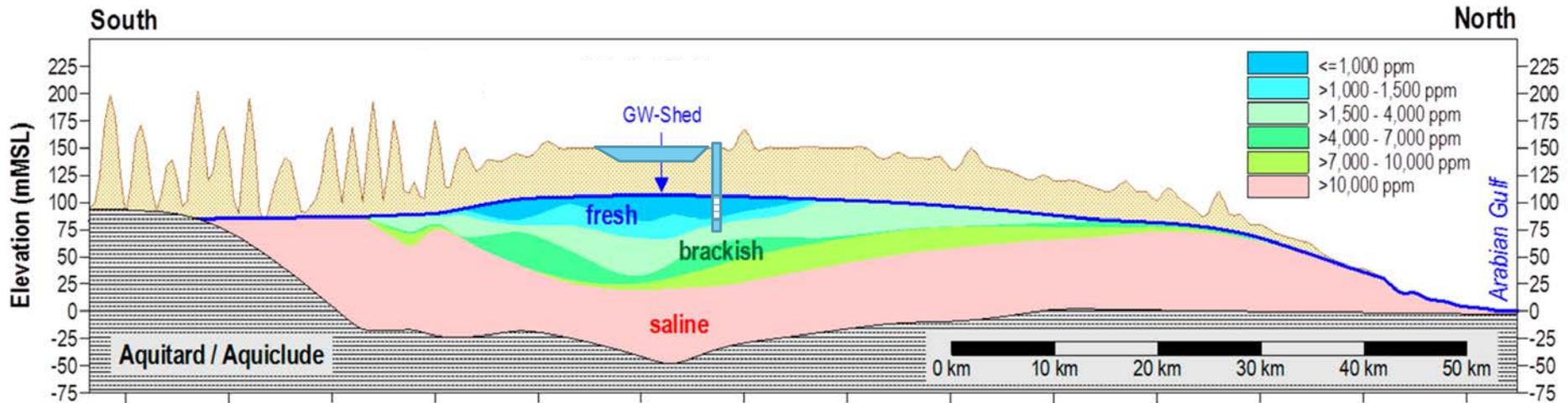


Degree of Difficulty Assessment (cont.)

For our hypothetical case study –

Information Required	Degree of Difficulty
10. Protection of water quality in unconfined aquifers	
<p>If unconfined and intended recovery is for drinking water supplies, then overlying land and waste disposal requires careful land management</p> <p>(In Perth, contaminated sites need to be identified also)</p>	<p>If recharge is to an unconfined aquifer for drinking water supplies then risk of contamination from land and waste management is high, and will require higher level of monitoring and assessment.</p> <p>Similarly, higher level of monitoring and assessment will be required where contaminated sites exist.</p> <p>Risk of recharging near contaminated sites – DWER contaminated site register to be checked in Stage 2</p>
11. Fractured rock, karstic or reactive aquifers	
<p>If aquifer is fractured rock or karstic, the ability to recover stored water will require evaluation, particularly where native groundwater is saline, or there is a steep hydraulic gradient.</p> <p>A larger attenuation zone will be necessary due to more rapid migration of recharge water.</p>	<p>If the aquifer is fractured rock or karstic media then the risk of migration of stored water is high. Recovery efficiency may be compromised and attenuation capacity will be reduced.</p> <p>A risk in the Tamala Limestone – recovery efficiency and attenuation to be assessed.</p>

Fractured or karstic aquifers



Representative cross-section, for illustrative purposes only. (Stuyfzand et al 2017)

Thickness of lens will depend on:

- Aquifer transmissivity
- Volume recharged
- Volume abstracted

Recovery efficiency will depend on:

- Groundwater salinity
- Pumping regime
- Bore construction

Degree of Difficulty Assessment (cont.)

For our hypothetical case study –

Information Required	Degree of Difficulty
12. Similarity to successful projects	
<p>Guidelines seek to encourage sharing of validation and verification data for all MAR projects, along with supporting operational data.</p> <p>Data is of value for future MAR projects, improving design and operation and reducing costs.</p>	<p>If the project is in the same aquifer with similar source as an operational MAR site, the data from the existing project should be taken into account when designing the new project.</p> <p>High degree of filtration/treatment likely to be required</p>
13. Management capability	
<p>Proponent new to MAR operation needs to gain appropriate expertise in parallel with Stage 2</p>	<p>If the proponent has experience with operating MAR sites with the same or higher degree of difficulty, or with water supply operations involving a structured approach to water-quality risk management, there is a low risk of water-quality failure due to operator inexperience.</p> <p>If not, the proponent should gain instruction in operating such systems, or engage a suitable manager, to reduce risk of failure of the pre-commissioning trial</p> <p>To be assessed and addressed by proponent</p>

Degree of Difficulty Assessment (cont.)

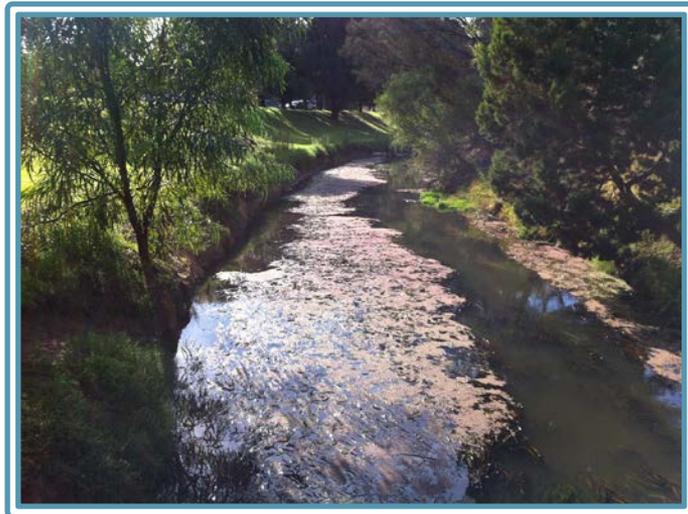
For our hypothetical case study –

Information Required	Degree of Difficulty
14. Planning and related requirements	
<p>Planning and related requirements include:</p> <ul style="list-style-type: none">• Proximity to neighbours• Safe public access or exclusion• Engineering for water holding structures• Location, dimension and design of any buildings or treatment plants• Power and water connections• Nuisance insect abundance before and after construction• Noise emissions from any mechanical plants and abatement measures• Earthmoving and construction plans• Neighbourhood engagement• Planning regulations	<p>If the site is in a built up area; built on public, flood-prone or steep land; close to a property boundary; contains open water storage or engineering structures; likely to cause a public health or safety concern; or at risk of creating an adverse environmental impact, there will be additional information and steps in the design.</p> <p>If not, the process for development and approval will be much simpler.</p> <p style="text-align: right;">Site specific</p>

Answers are indicative only – they suggest the of level of effort required for Stage 2 investigations

Stage 1 – Conclusions Hypothetical Case Study

- MAR scheme appears technically viable, subject to confirmation of adequate source water (Table 4.3)
- Proponent to review the degree of difficulty (Table 4.4) and ability of the proposed scheme to meet their objectives and decide whether to proceed.
 - Provide an indicative volume to be recharged/recovered
 - Preliminary conceptual plan for MAR scheme
 - Indicate where highest risks lie and further information required
 - Provide outline of scope and indicative costs for Stage 2 Investigations



Water Corporation Main
Drain – May 2017

Estimated flow – 6 ML/d

Stage 2 – Investigations and Risk Assessment

■ Investigations:

- Source water and groundwater sampling and analysis
- Hydrogeological studies
 - Drilling investigations
 - Aquifer testing
 - Conceptual hydrogeological model
- Catchment studies
 - Land use
 - Drainage
 - Topography
- Basic groundwater modelling
- Geochemical evaluation

■ Maximal risk assessment:

- Estimate the maximum risk and evaluate uncertainty
 - Chapter 5 MAR Guidelines
 - Low inherent risk => commissioning trials
 - Moderate or high risk => identify preventative measures (management strategies)



Drilling investigations – Gngangara Mound

Stage 2 – Investigations and Risk Assessment



Filtration system – Hartfield Park, Amiad Brochure

- Document preventative measures
 - Operational procedures, critical control points, contingency plans
 - Model and validate effects
 - If measures not effective or feasible to implement => project is not viable
 - If effective and feasible to implement => undertake residual risk assessment.

- Residual risk assessment (level of risk with preventative measures in place)
 - Moderate to high risk
 - Identify further preventative measures – reiterative process
 - Low residual risk
 - Develop and cost functional design for pilot scheme
 - Business case for pilot scheme

Stage 3 – Construction and Commissioning

- Construct project and perform trials
 - Commission
 - Trial and validate preventative measures
- Operational residual risk assessment
 - Evaluate risk and uncertainty with preventative measures in place
 - Moderate or high residual risk – identify preventative measures (trial and validate)
 - Low inherent risk – move to operational scheme
- Functional design
 - Design and cost full scale scheme
 - Business case for full scheme
 - Refine risk management plan



Hartfield Park ASR Pilot Scheme – Shire of Kalamunda

Project shown to be viable  Stage 4 – Operational Scheme

Hartfield Park

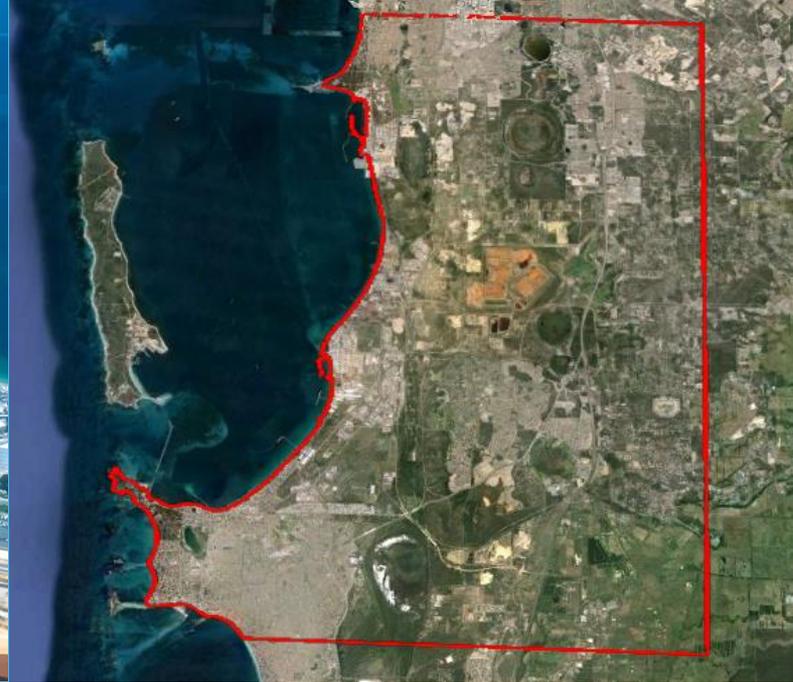
A MUNICIPAL SCALE ASR PROJECT

Questions?

Karen Johnston – Managed Recharge

Level 24 Allendale Square | 77 St Georges Terrace | PERTH WA 6000

0407 198 398 | karen.johnston@managedrecharge.com.au | www.managedrecharge.com.au



Feasibility of MAR using Recycled Water to meet industrial demand in Kwinana WA

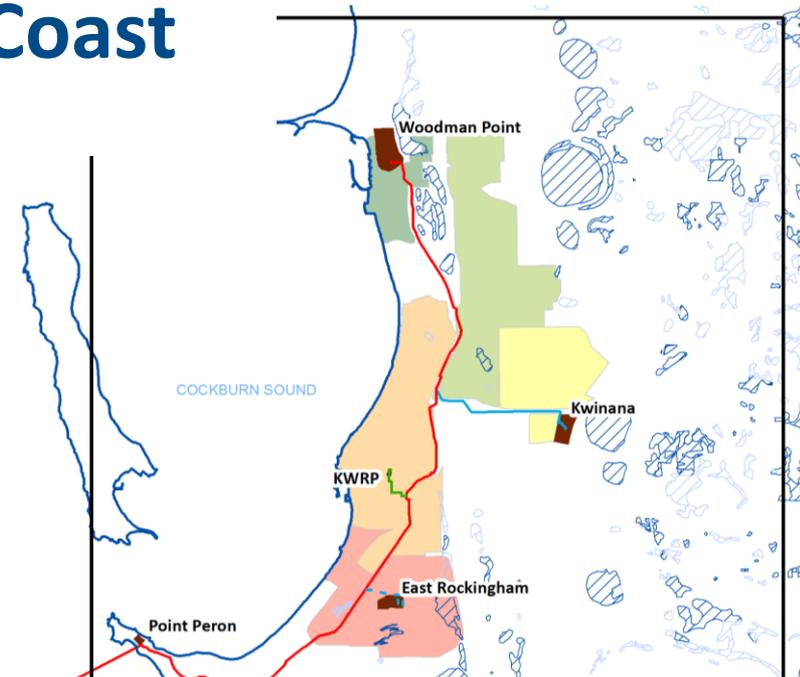
Mike Donn | MAR Essentials Workshop
26-27 October 2017

CSIRO LAND AND WATER
www.csiro.au

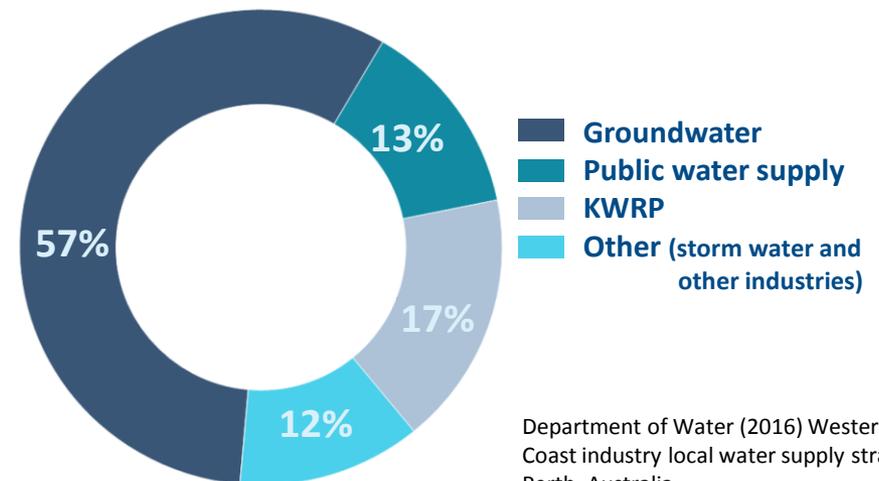


Water use in Western Trade Coast

- Western Trade Coast is WA's largest industrial precinct
- History of falling GW levels and seawater intrusion
- Groundwater demand high
 - Long-term security of groundwater supply under threat (climate change)
 - Water is limiting factor for industrial growth (future demand exceeds supply)



Current water supplies to meet demand
(Department of Water, 2016)



Department of Water (2016) Western Trade Coast industry local water supply strategy. Perth, Australia.

Recycling water for heavy industry and preventing sea water intrusion

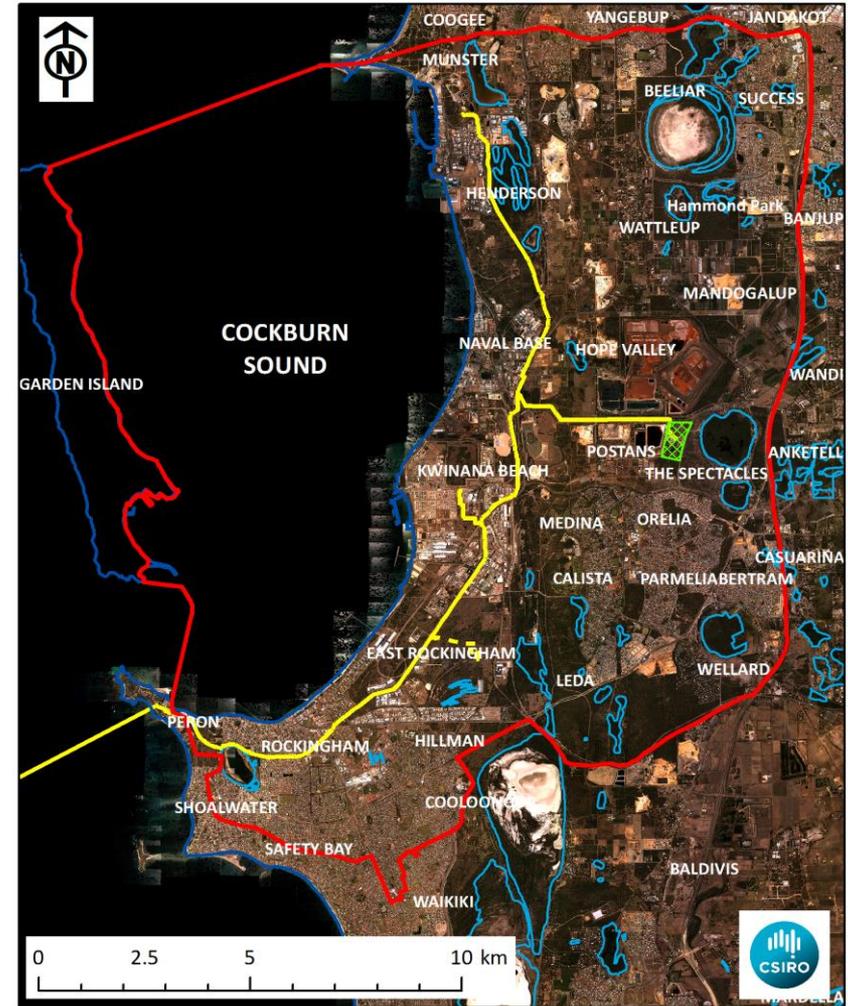
Study to identify the feasibility of diverting treated wastewater to the Superficial Aquifer in the Cockburn Sound Catchment

Opportunities include:

- non-potable water source for industry, councils, residents
- reverse salt water intrusion
- recovery of wetlands
- help clean up contamination
- proof-of-concept for other areas

Main risks are:

- increased N loads into Cockburn Sound
- mobilising pollutants
- surface expression of infiltrated water



Australian Water Recycling
Centre of Excellence



Methodology

- Groundwater modelling
 - Impacts of climate/abstraction on GW levels
 - Impacts of MAR on GW levels – Two infiltration rates (4.8 & 9.6 ML/d)
 - MAR scenarios + ‘Business As Usual’
 - Calibration period (1990-2012) + projected period (2012-2032)
- Environmental and Engineering constraints
 - Wetlands + groundwater users + inundation + N export
 - Infiltration system design (gallery vs basin) and costs (*GHD*)
 - Investigation of pre-treatment options (suspended solids & nitrogen) (*GHD*)
- Economic assessment
 - Identify the benefits of groundwater recharge
 - Evaluate the benefits vs costs of each MAR option for key sites

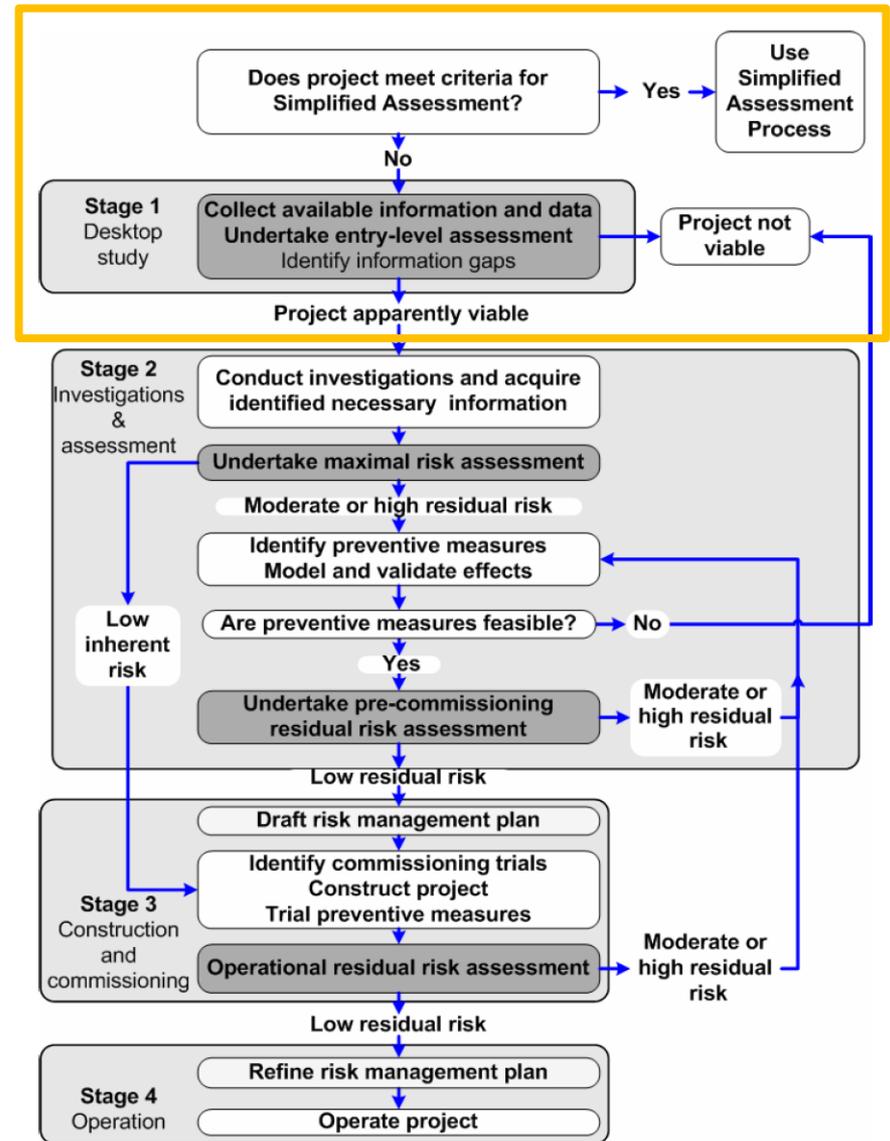
Assessment approach

- Assessment based on “MAR guidelines”
- Stage 1 – Entry Level Assessment

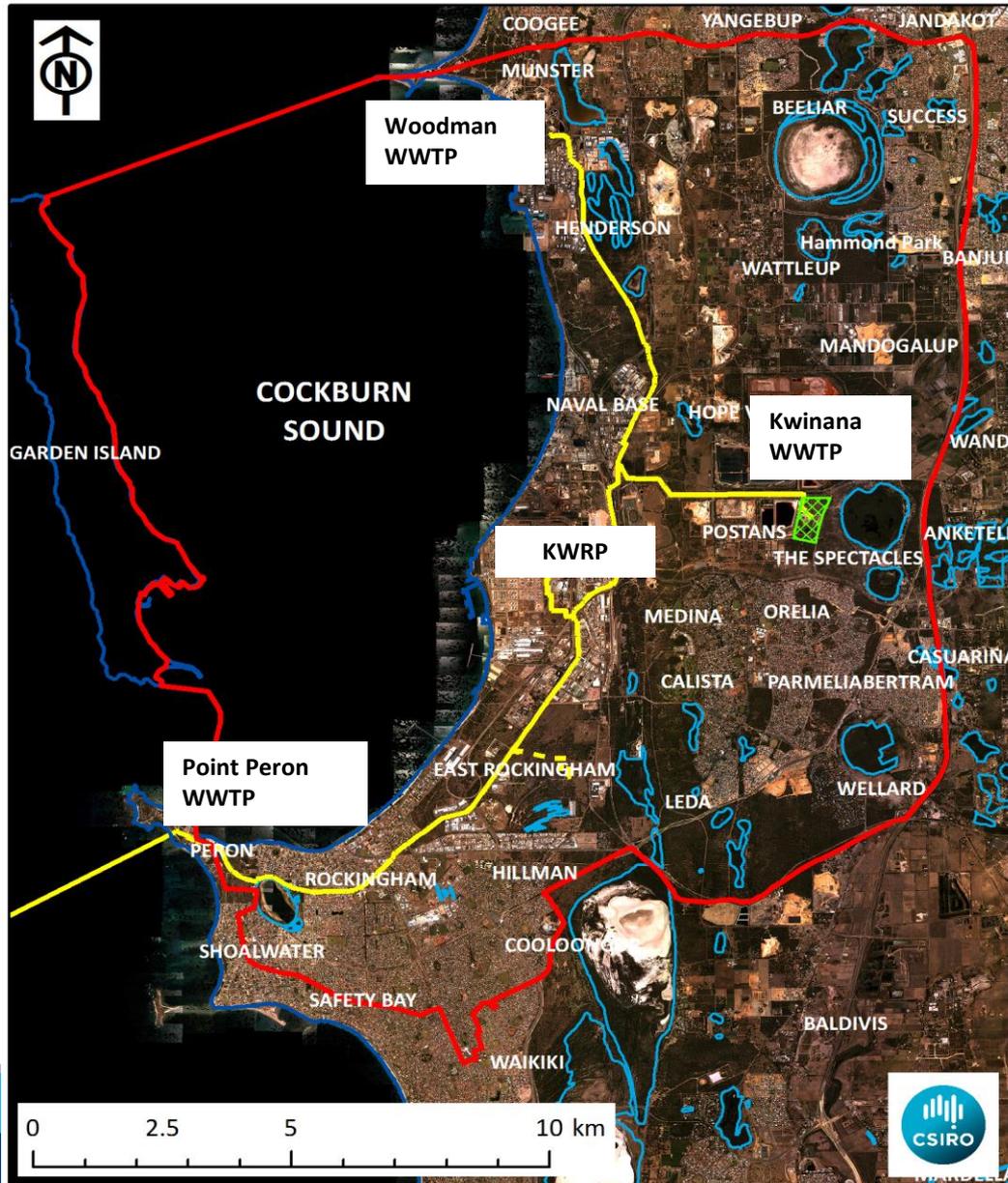
Part 1 – Viability assessment

Part 2 – Degree of difficulty assessment

- Available TWW and groundwater quality data
- Hydrogeology
- Groundwater modelling
- Analogous MAR site → Kwinana WWTP infiltration

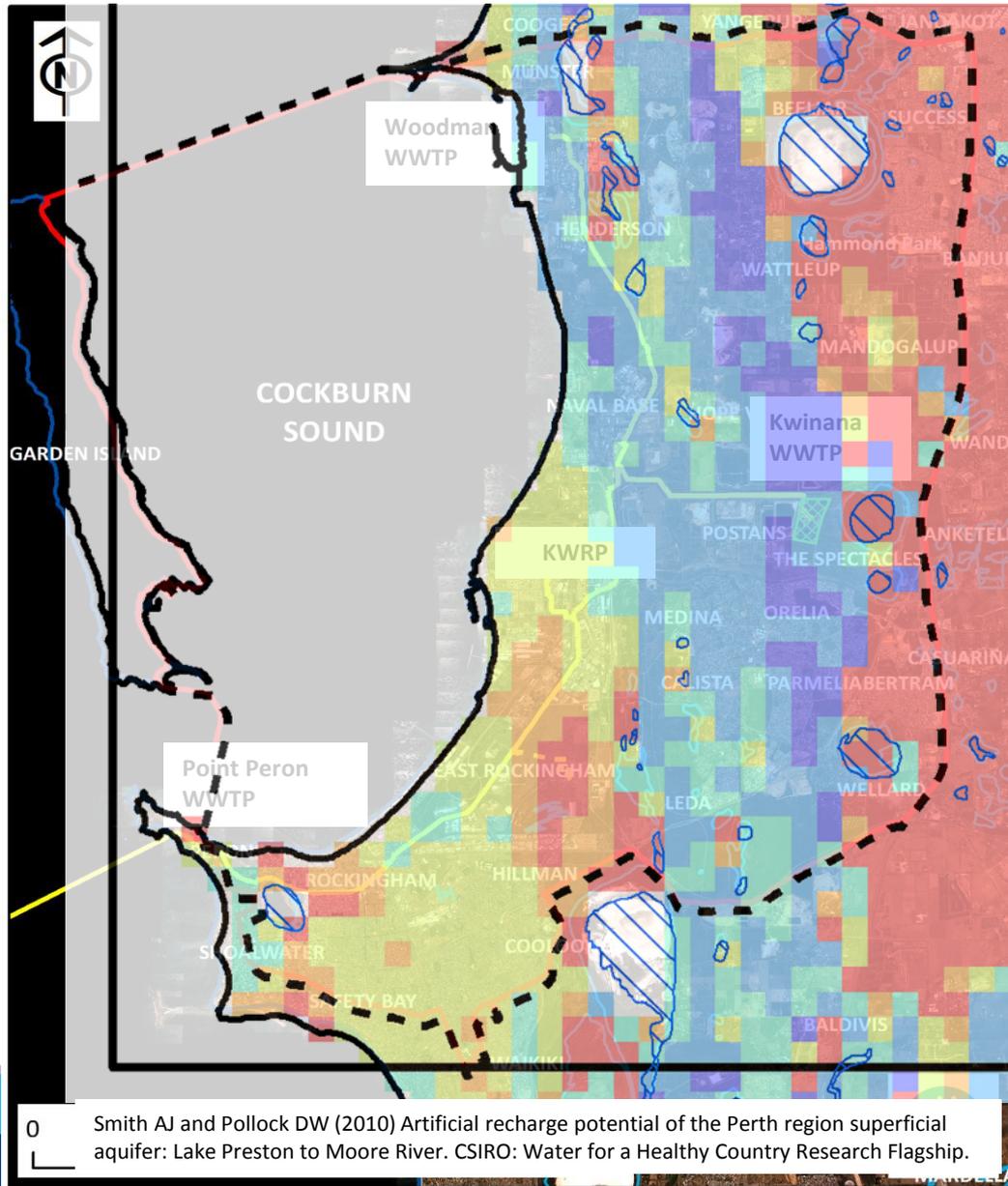


Viability assessment



1. Demand from Industry
2. Source water availability
 - TWW from SDOOL
 - TWW from Kwinana WWTP
3. Hydrogeological assessment
 - Existing infiltration at Kwinana WWTP
 - Large areas suitable for MAR (Smith & Pollock, 2010)
4. Space for water capture and treatment
5. Capability to design, construct and operate

Viability assessment



1. Demand from Industry
2. Source water availability
 - TWW from SDOOL
 - TWW from Kwinana WWTP
3. Hydrogeological assessment
 - Existing infiltration at Kwinana WWTP
 - Large areas suitable for MAR (Smith & Pollock, 2010)
4. Space for water capture and treatment
5. Capability to design, construct and operate

Wastewater discharge to ocean and aquifer (Water Corporation 2013/14)

Ocean outfalls

– Alkimos	7.3
– Ocean Reef	50.0
– Swanbourne	22.3
– <u>Point Peron</u>	<u>58.4</u>
Total	138 GL/yr

Coastal infiltration sites

– Yanchep	0.27
– Kwinana	1.8
– Gordon Rd	3.5
– Halls Head	1.1
– <u>Caddadup</u>	<u>0.56</u>
– Total	7.23 GL/yr

Beenyup Groundwater Replenishment

– 3 year trial (2012)	1.2 GL/yr
– Stage 1	14.0 GL/yr
– Stage 1 & 2	28.0 GL/yr



Degree of difficulty assessment

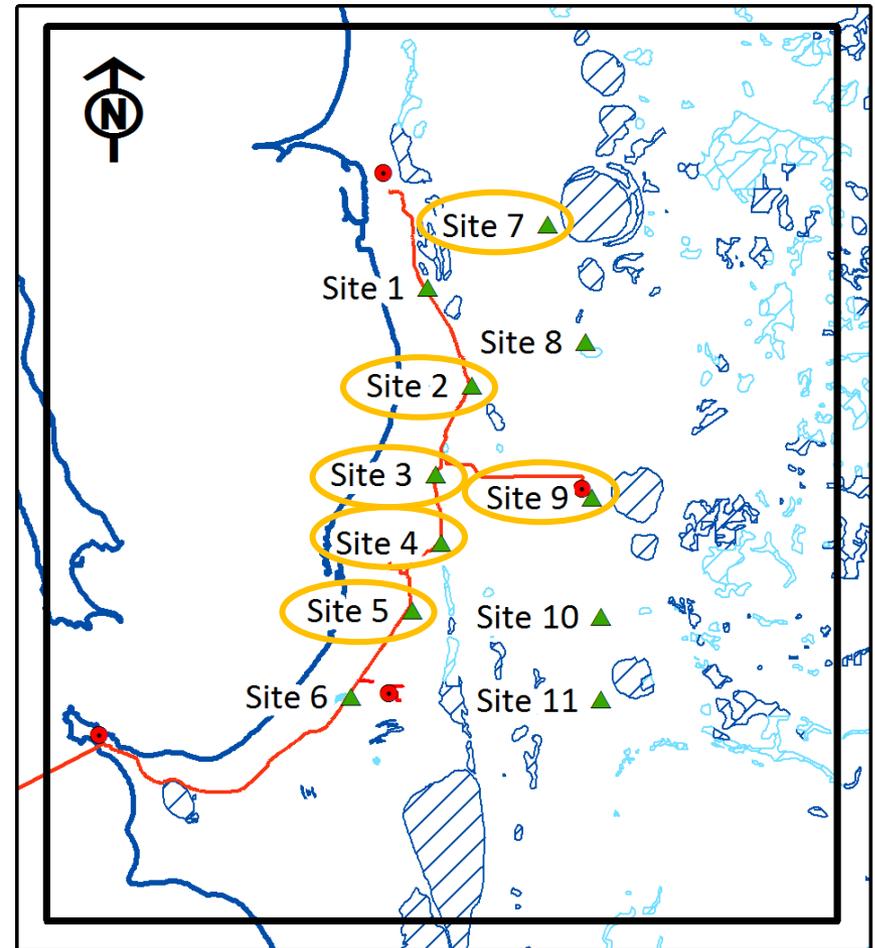
Fourteen topics/questions

- Water quality assessments (7)
 - Source water relative to existing groundwater and end-use/s
 - Desktop assessment of water quality datasets
- Groundwater users (1)
 - Existing groundwater uses
 - Particle tracking in groundwater model & constraints mapping (GIS)
 - GDEs
 - Groundwater modelling outputs
- Aquifer capacity and hydrogeology (3)
 - e.g. inundation
 - Analysis of Kwinana WWTP
- Similarity to successful projects (1)
 - *Generally not assessed*
- Management capability and Planning (2)

Groundwater model scenario development

1. Preliminary groundwater modelling (12 sites)
 - Regional hydrogeological influences on MAR
 - Infiltration rate
2. Environmental and engineering constraints (6 sites)
 - Site suitability/land availability
 - Wetlands
 - Distance to coast

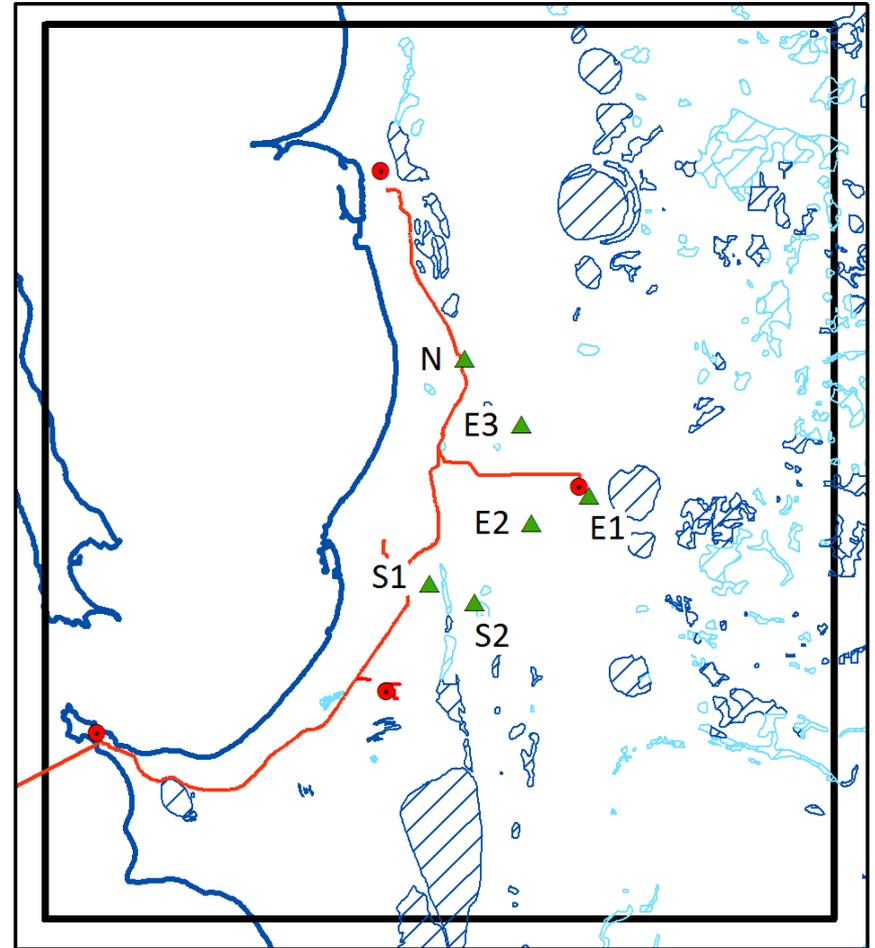
Based on PRAMS and local models developed by Nield (1999; 2004) with a refined grid and hydraulic conductivity zonation



Groundwater model scenario development

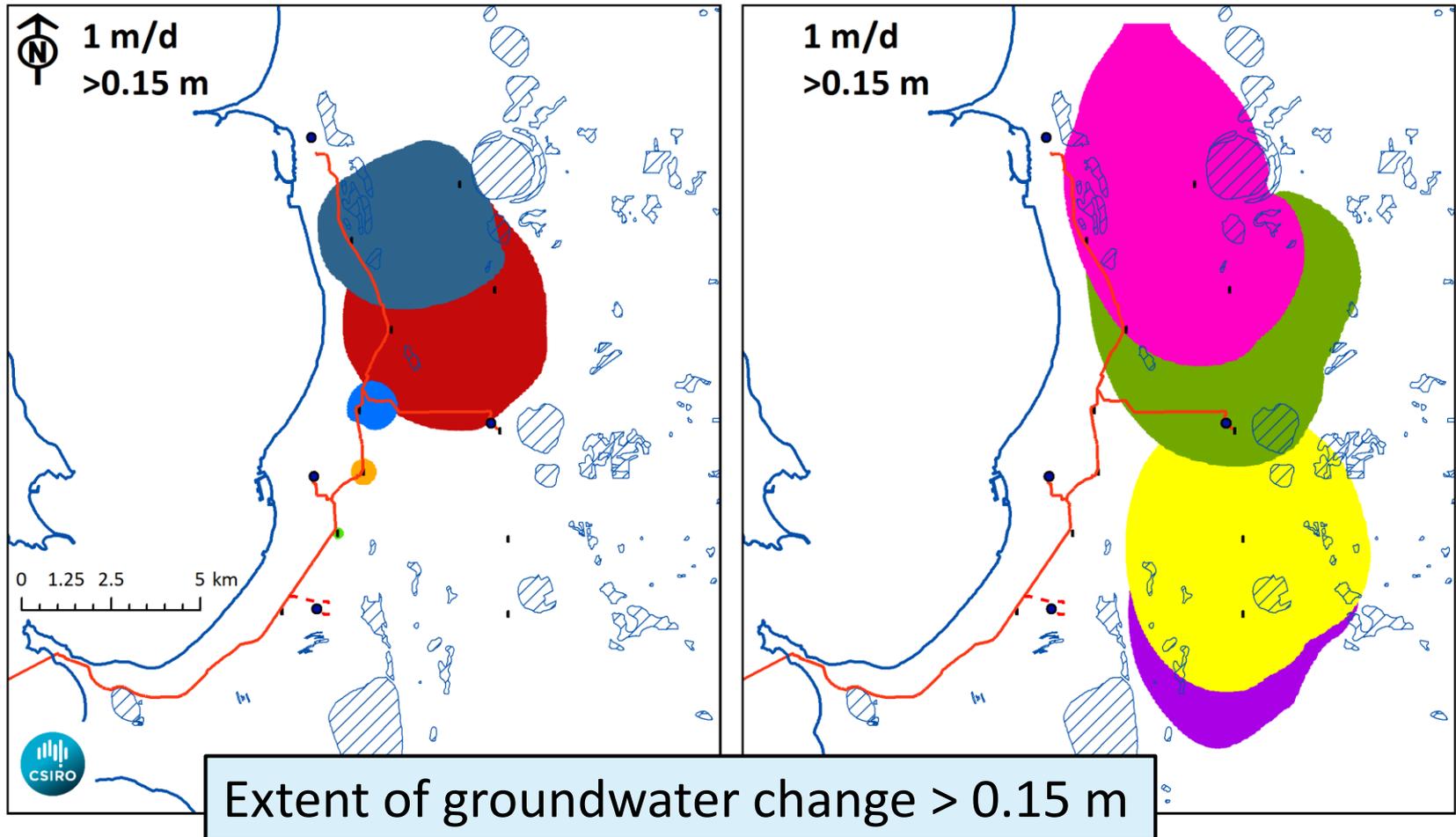
1. Preliminary groundwater modelling (12 sites)
 - Regional hydrogeological influences on MAR
 - Infiltration rate
2. Environmental and engineering constraints (6 sites)
 - Site suitability/land availability
 - Wetlands
 - Distance to coast
3. Final site assessments (6 sites)

Based on PRAMS and local models developed by Nield (1999; 2004) with a refined grid and hydraulic conductivity zonation



Preliminary groundwater modelling

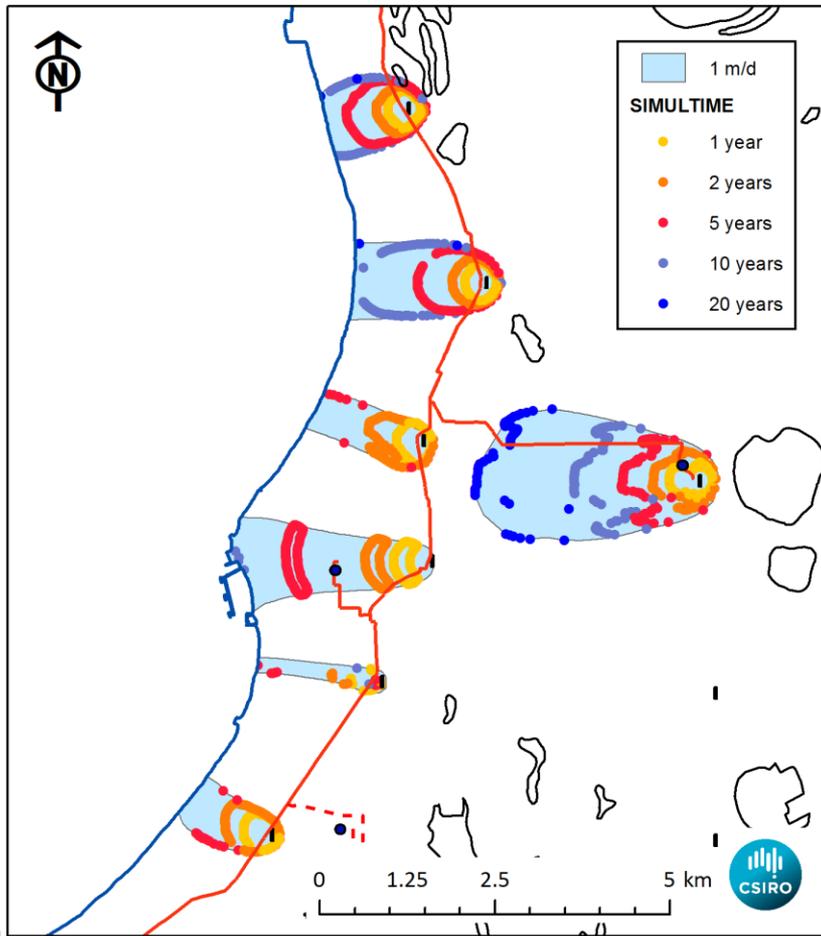
Change in groundwater level



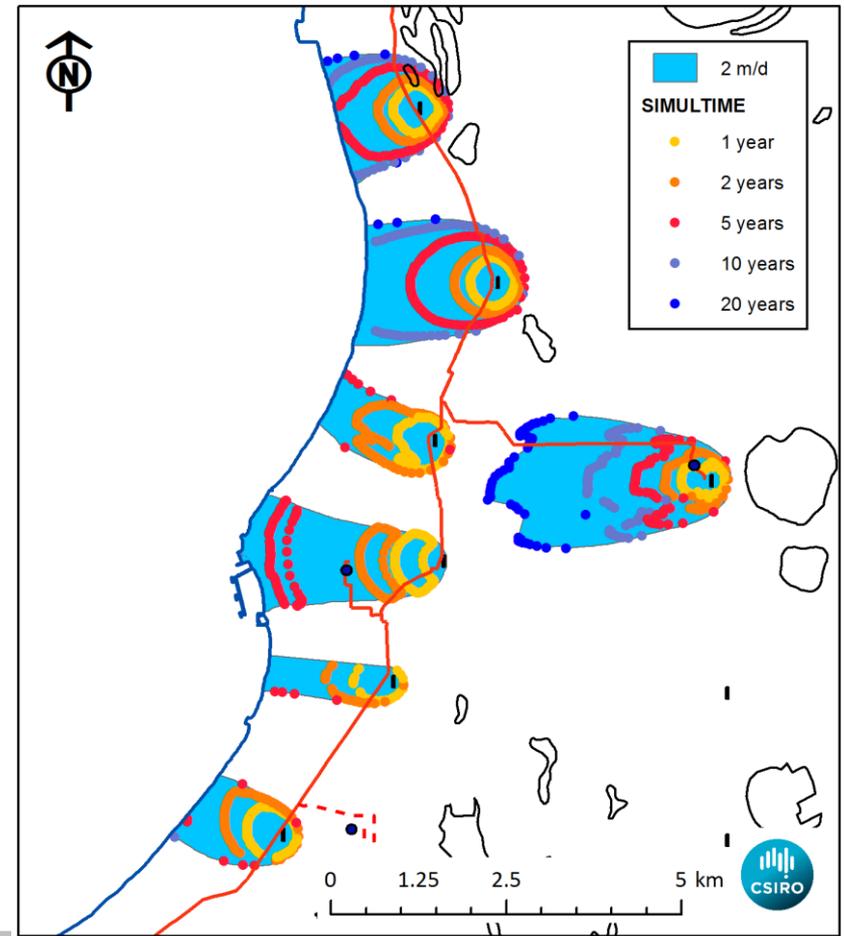
Preliminary groundwater modelling

Particle travel time

Infiltration rate = 1 m/d

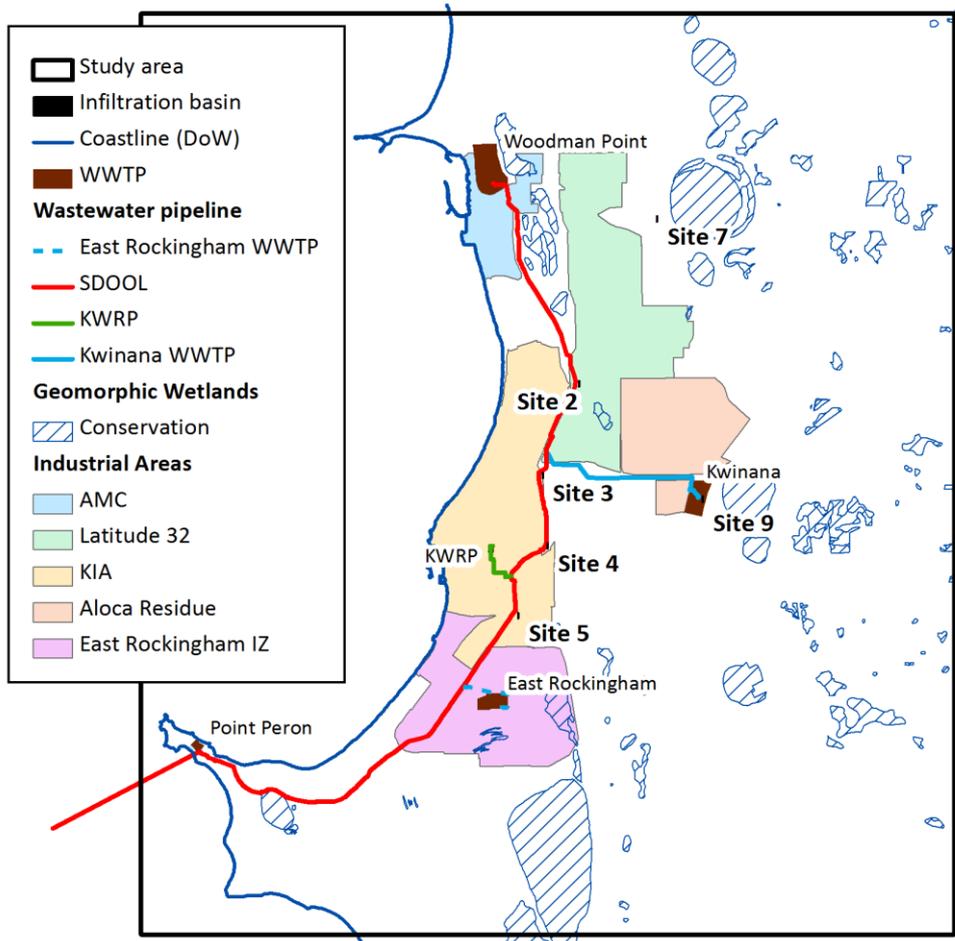


Infiltration rate = 2 m/d



Environmental and engineering constraints

Aquifer capacity



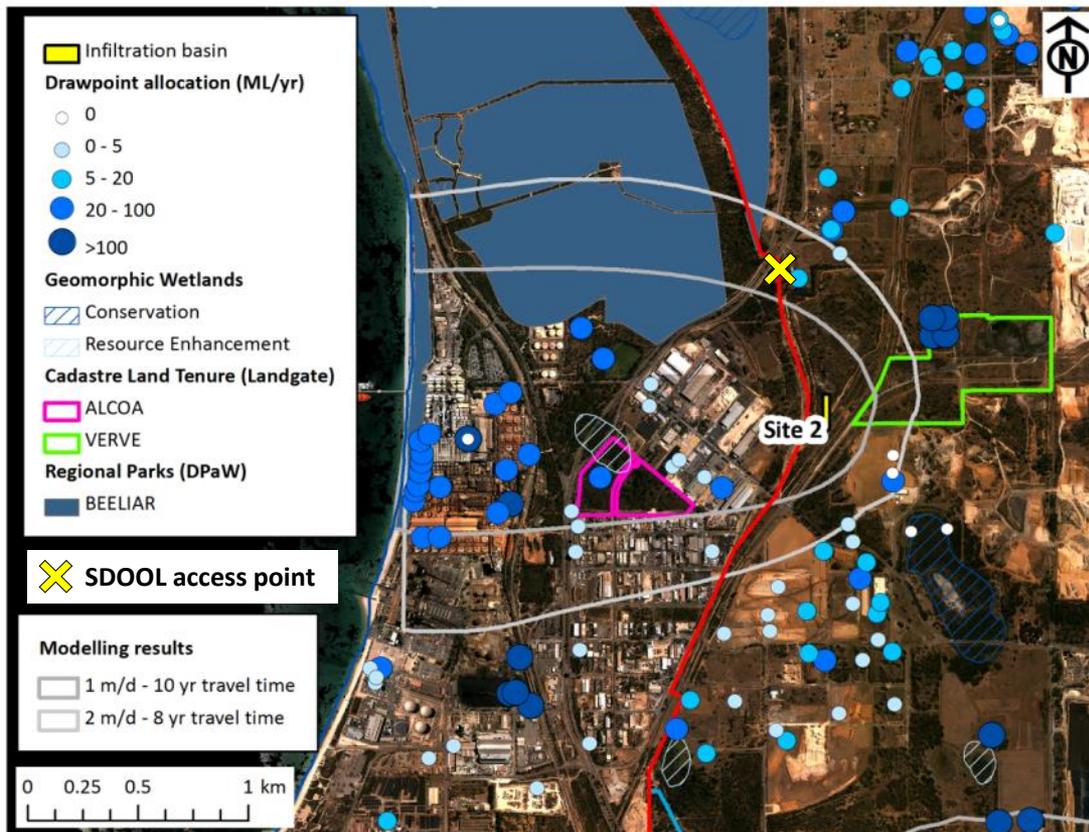
Does the aquifer have the capacity to accept infiltrated TWW?

→ Inundation does not occur in the vicinity of the model basins

SITE	DEPTH TO GW NO MAR (m)	MAR MOUND HEIGHT (m)
2	8	1.5 – 3.0
3	11	1.3 – 2.5
4	7.5 – 8.6	0.3 – 0.6
5	4.1	0.2 – 0.5
7	38 – 42	7 – 13
9	6.7 – 8.0	4 – 5

Environmental and engineering constraints

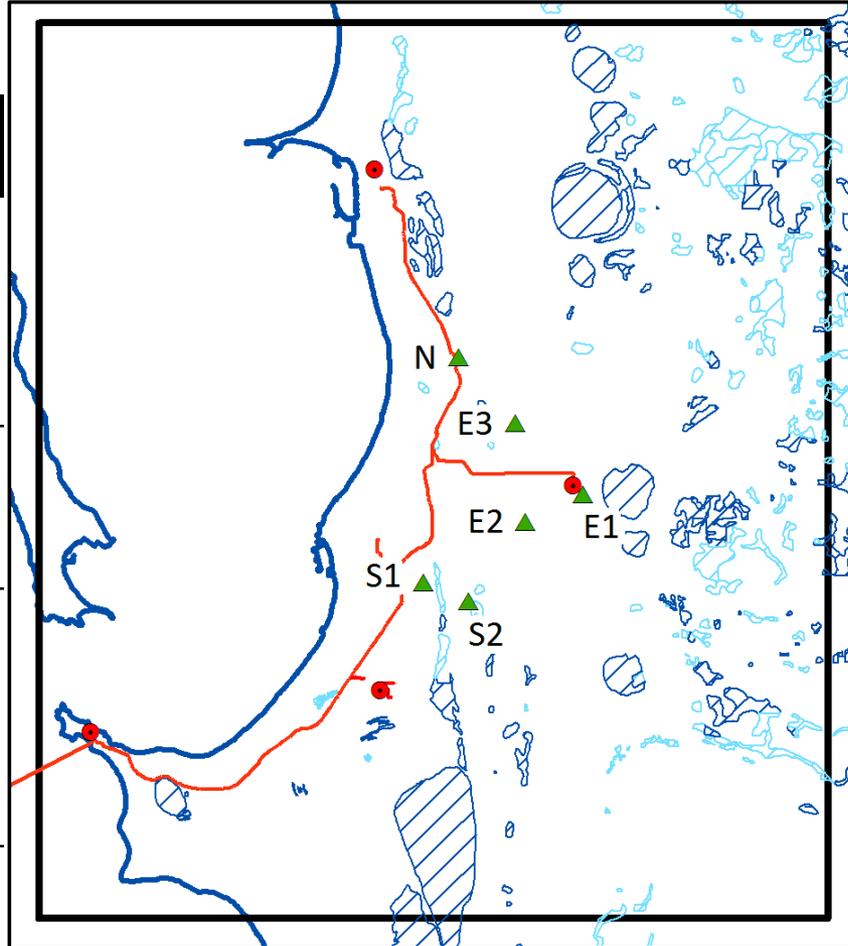
Existing groundwater users, connected ecosystems and property boundaries



- Groundwater users
 - Industrial – mainly Alcoa
- Wetlands
 - Long Swamp (up-gradient)
 - Resource enhancement wetland (down-gradient)
- Beeliar Regional Park
 - Limits MAR potential locations
- Cockburn Sound
 - Site 1.9 km from coast
- Contaminant mobilisation
 - Alcoa + fly ash

Final site assessments

MAR LOCATION	SOURCE WATER
Site N	SDOOL
Site S1	SDOOL
Site S2	SDOOL
Site E1	Kwinana WWTP
Site E2	Kwinana WWTP
Site E3	Kwinana WWTP

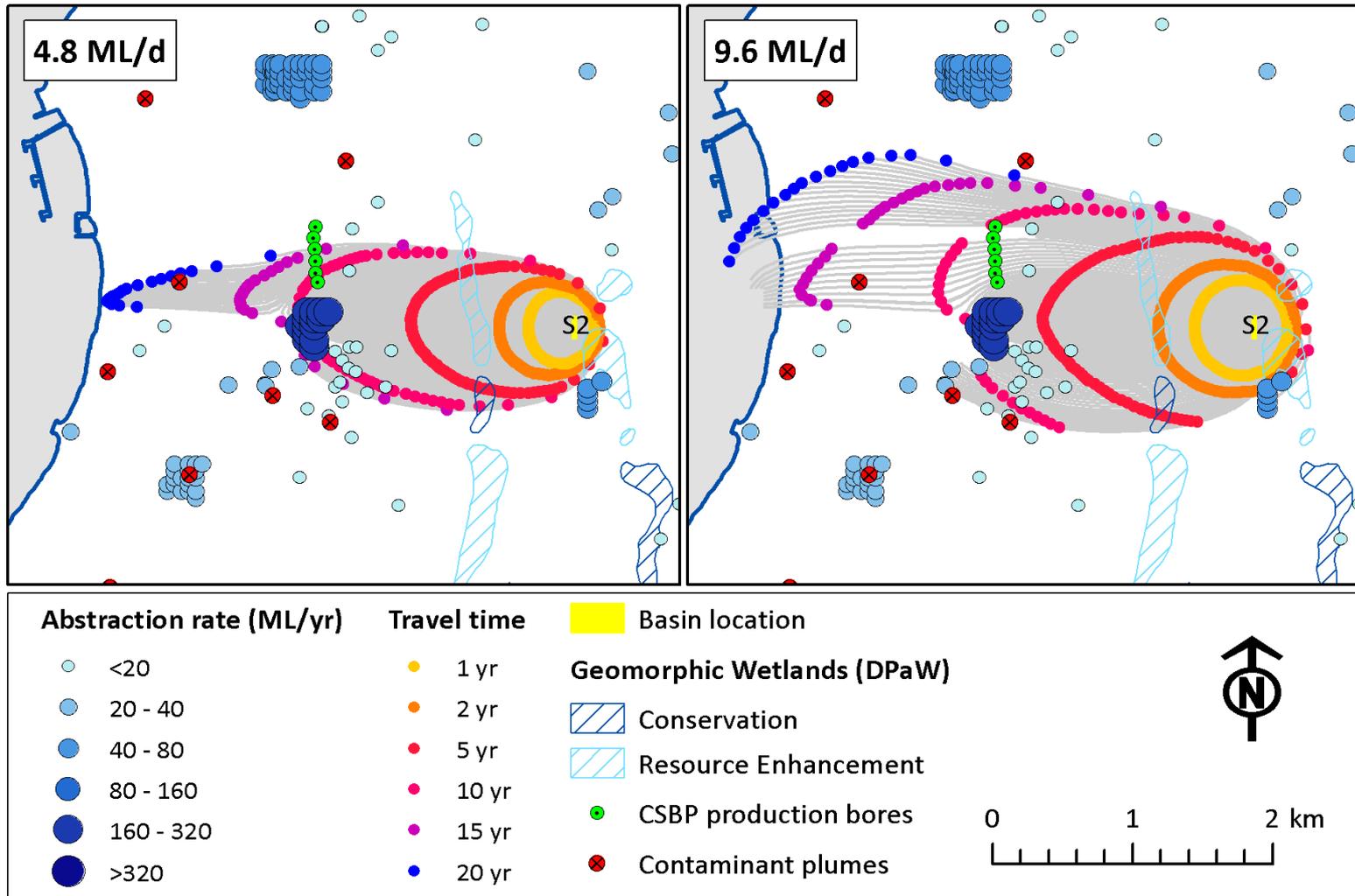


Final site assessments

MAR LOCATION	SOURCE WATER	SCENARIO INFILTRATION RATES	KWINANA WWTP OPERATION	ENGINEERING ASPECTS (GHD, 2015A)	COST-BENEFIT ANALYSIS
Site N	SDOOL				
Site S1	SDOOL	Constant	Continued operation at constant rate	Access to TWW	
Site S2	SDOOL	4.8 ML/d and 9.6 ML/d	4.7 ML/d	Transport of TWW and pipelines necessary	
Site E1	Kwinana WWTP	Increasing rate 4.9 ML/d up to 7.2 ML/d	As per scenario	Pre-treatment options for TWW (filtration and nitrogen removal)	Comparison of scenarios Based on engineering and other cost estimates
Site E2	Kwinana WWTP	Increasing rate (in excess from WWTP) 0.2 ML/d up to	Continued operation at constant rate	Infiltration options (recharge basin verses infiltrate gallery)	
Site E3	Kwinana WWTP	2.5 ML/d	4.7 ML/d	Estimate of associated cost	

Final site assessments

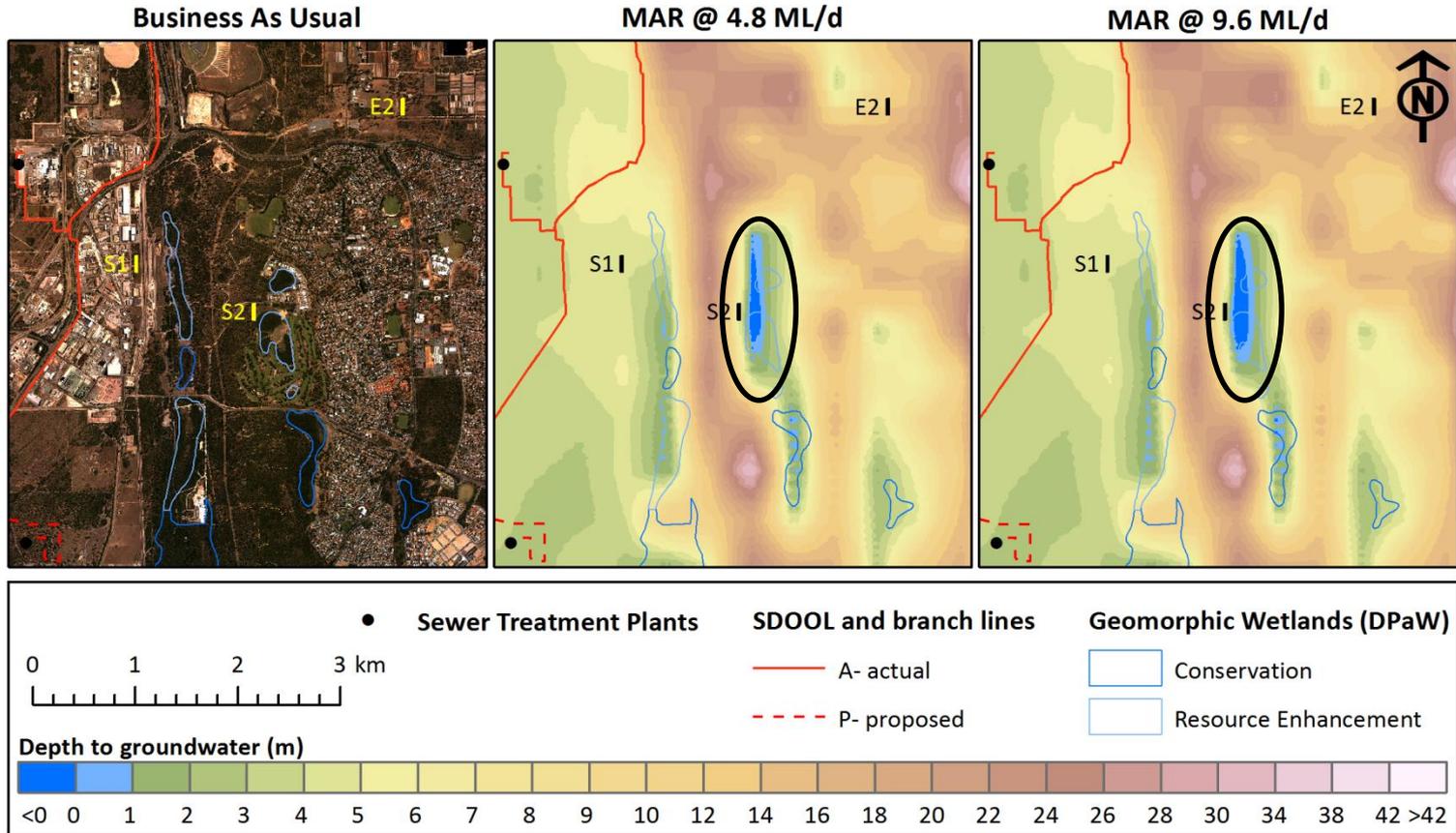
Residence time of MAR water – *Advective particle track*



Final site assessments

Depth to groundwater

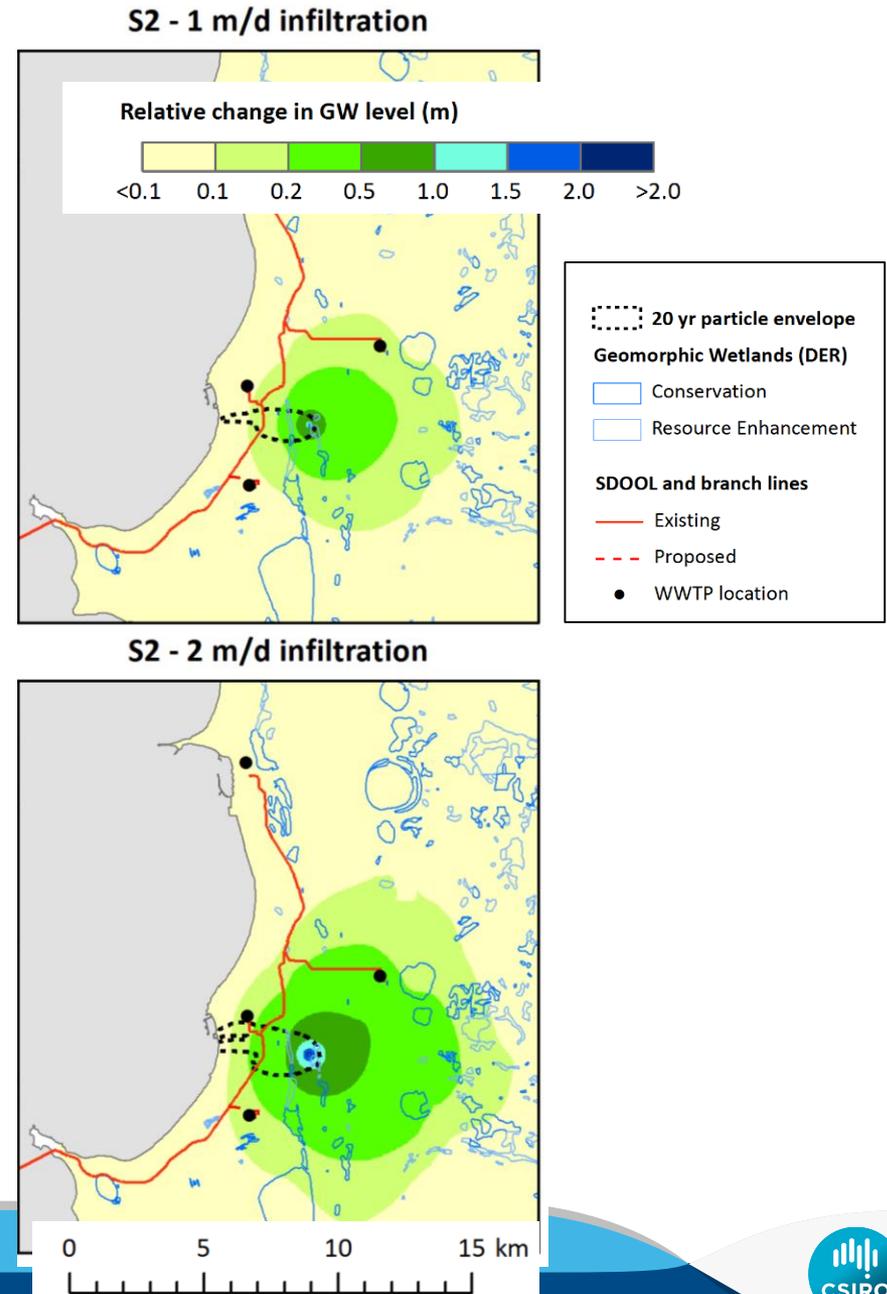
2032



Final site assessments

Groundwater level impacts

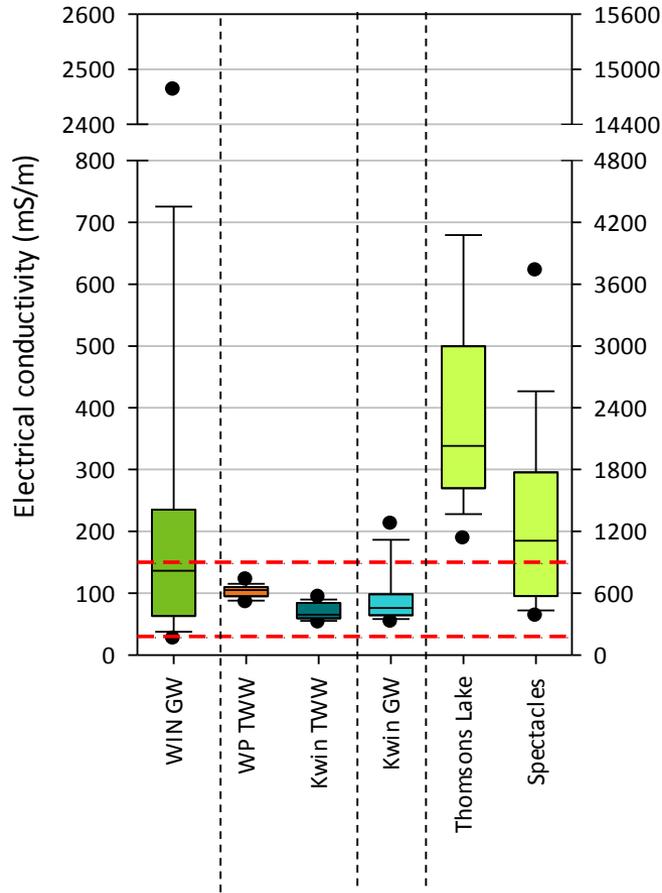
- GW level response to MAR substantial relative to 'plume' area
 - Positive environmental benefits
 - Benefits for groundwater users outside wastewater impacted zone



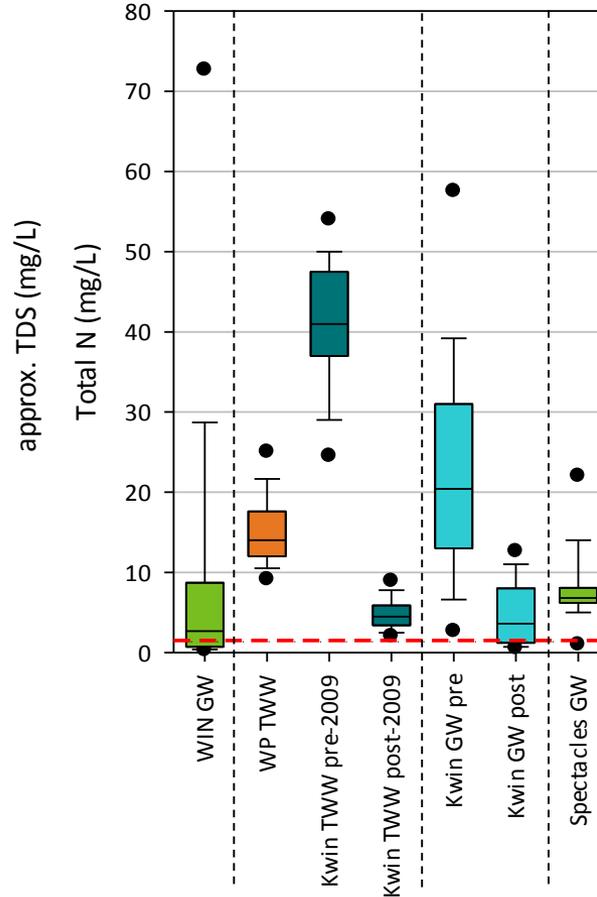
Water quality assessment

Source water quality with respect to groundwater environmental values

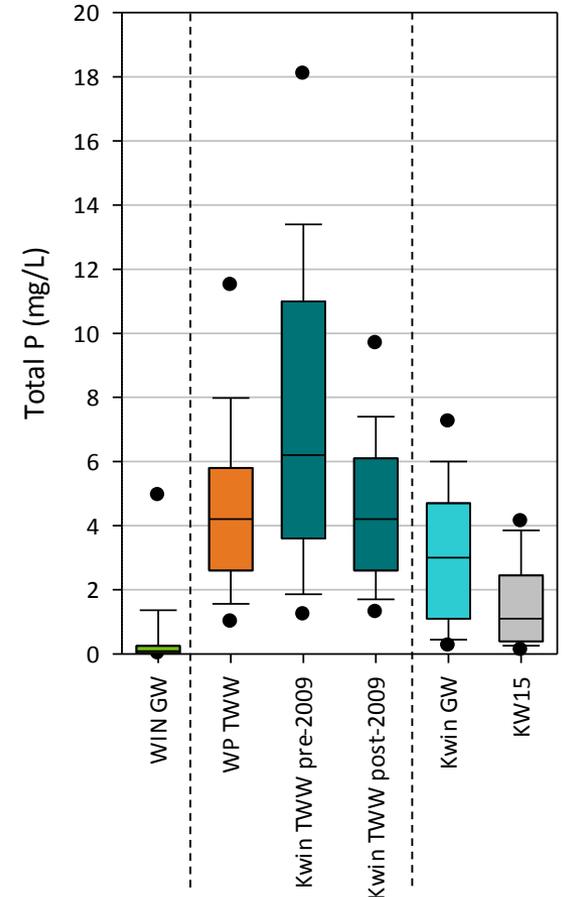
ANZECC TVal - Wetlands
EC = 30-150 mS/m



ANZECC TVal - Wetlands
TN = 1.5 mg/L



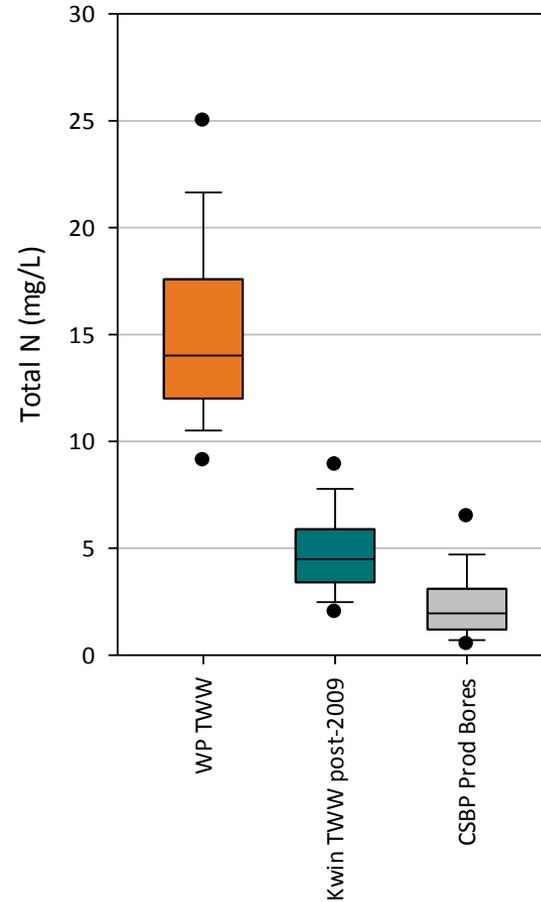
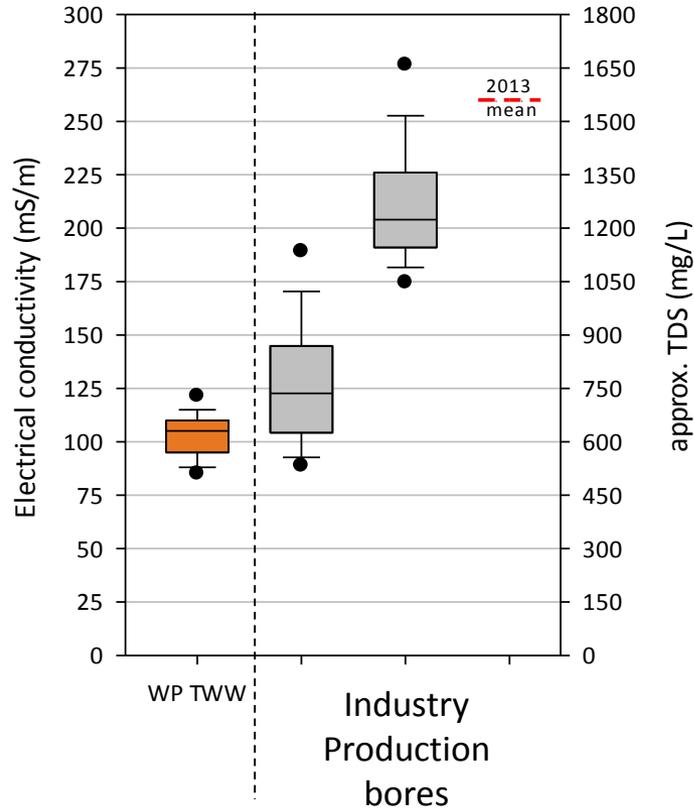
ANZECC TVal - Wetlands
TP = 0.06 mg/L



ANZECC Trigger value – Aquatic ecosystem trigger values slightly disturbed ecosystems

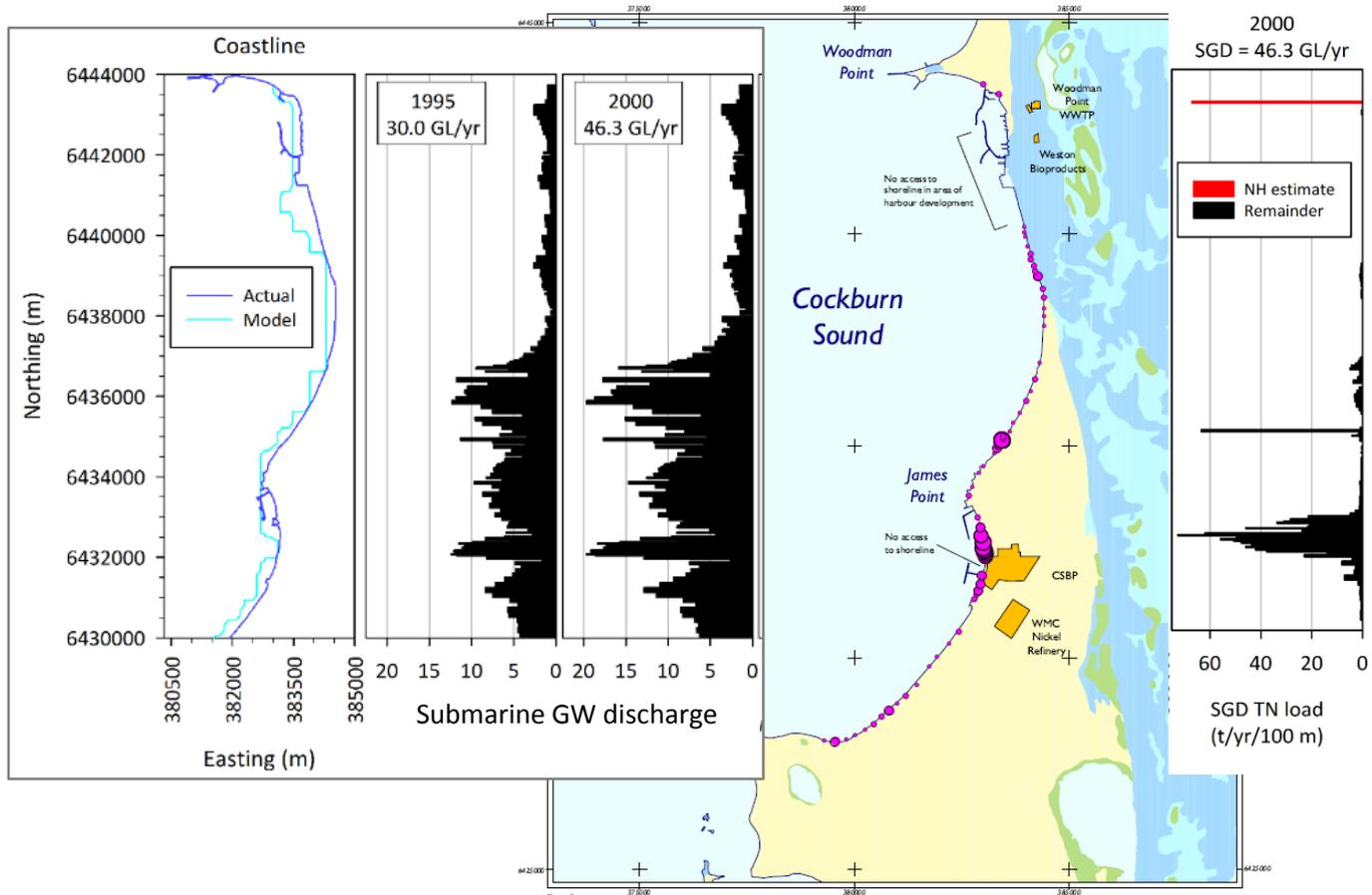
Water quality assessment

Source water quality with respect to recovered water end-use environmental values



Water quality assessment

Impact of MAR on marine environment



Water quality assessment

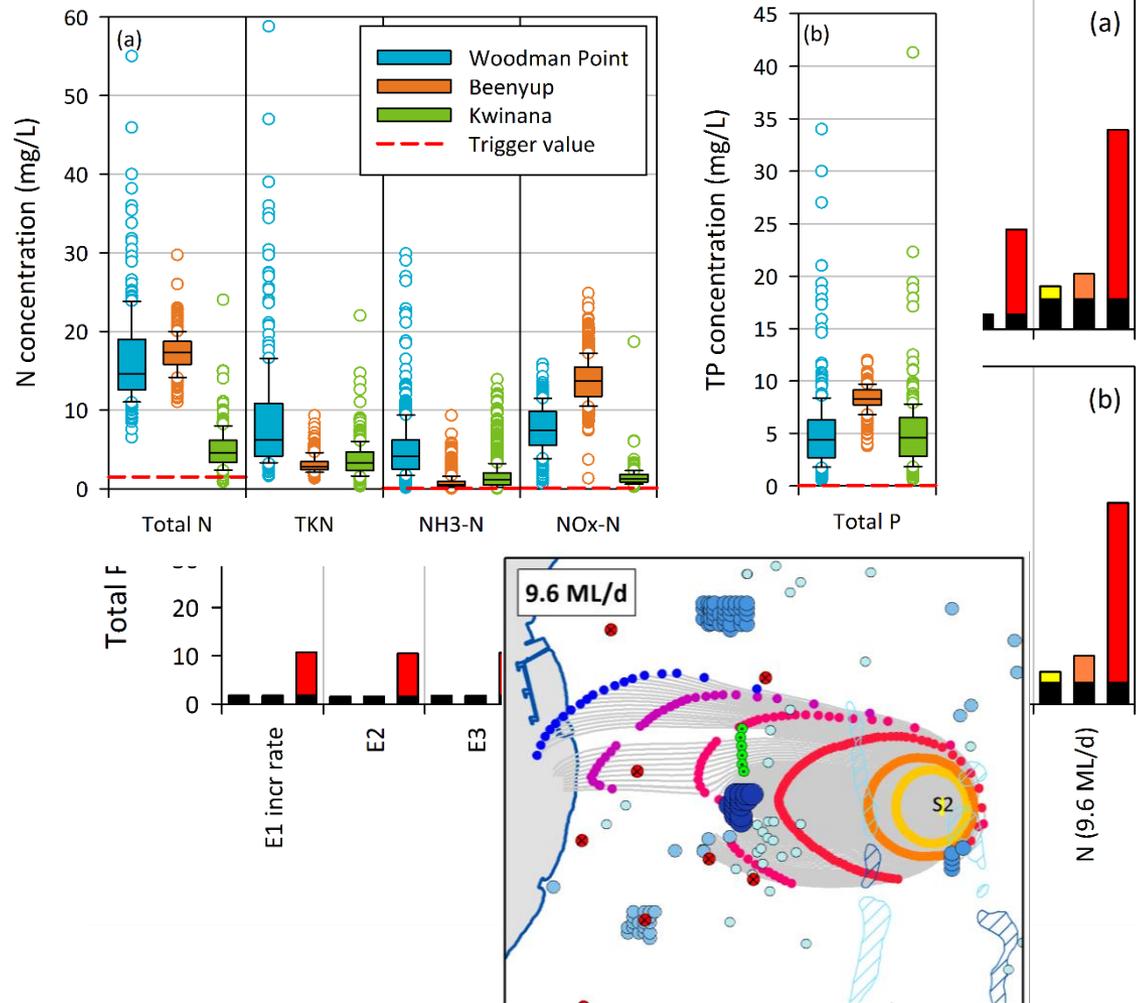
Sensitivity analysis changes to SGD nutrient loads (*End of projected period (2032)*)

Mobilisation of **existing** nutrients (I) due to increased SGD (*MAR minus BAU*)

and

Mobilisation of nutrients introduced with MAR

- (II) moderate case (50th)
- (III) high case (95th)
- (IV) worst case (95th + no interception)



Water quality assessment

Sensitivity analysis changes to SGD nutrient loads (*End of projected period (2032)*)

Mobilisation of **existing** nutrients (I) due to increased SGD
(*MAR minus BAU*)

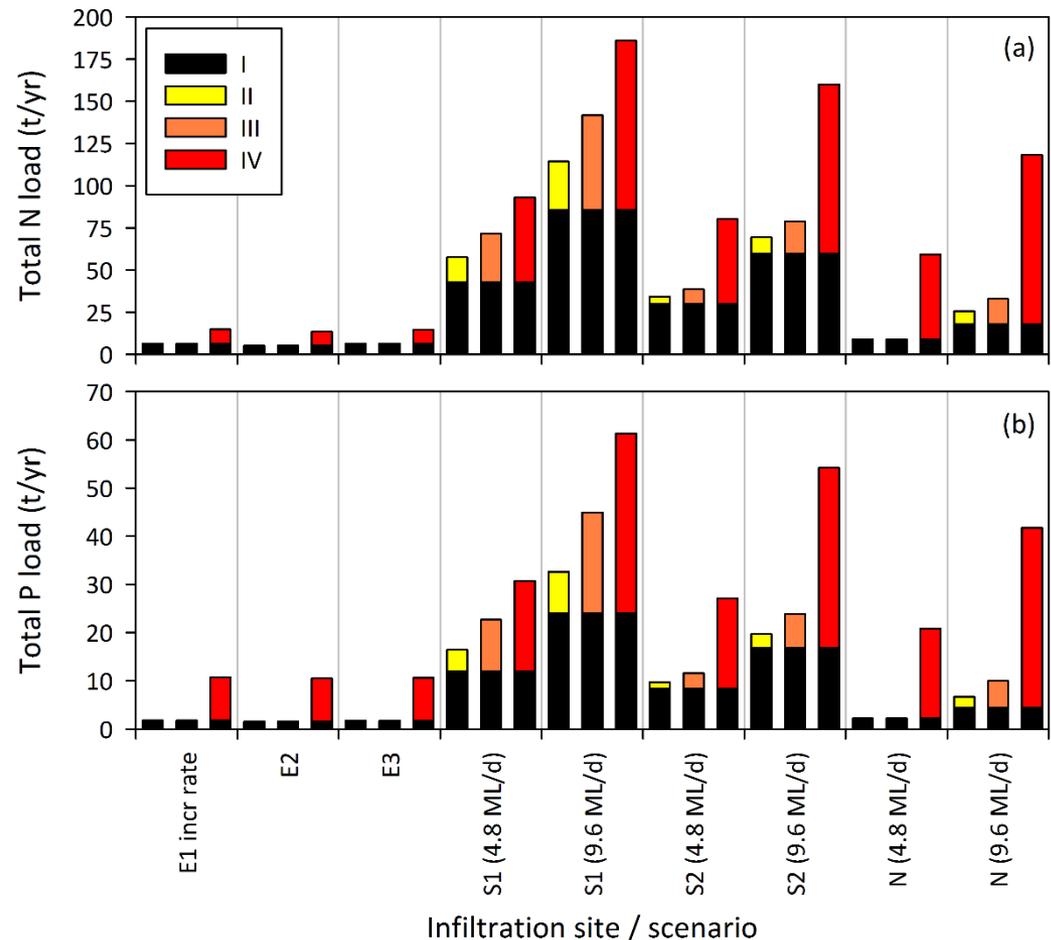
and

Mobilisation of nutrients introduced with MAR

(II) moderate case (50th)

(III) high case (95th)

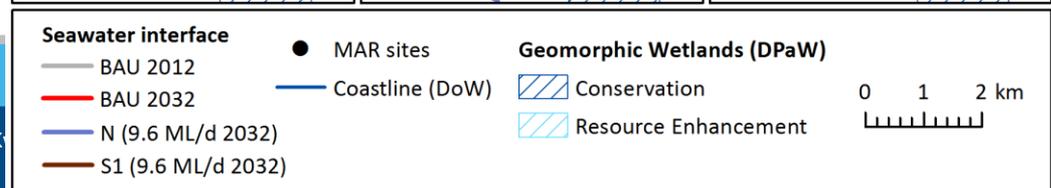
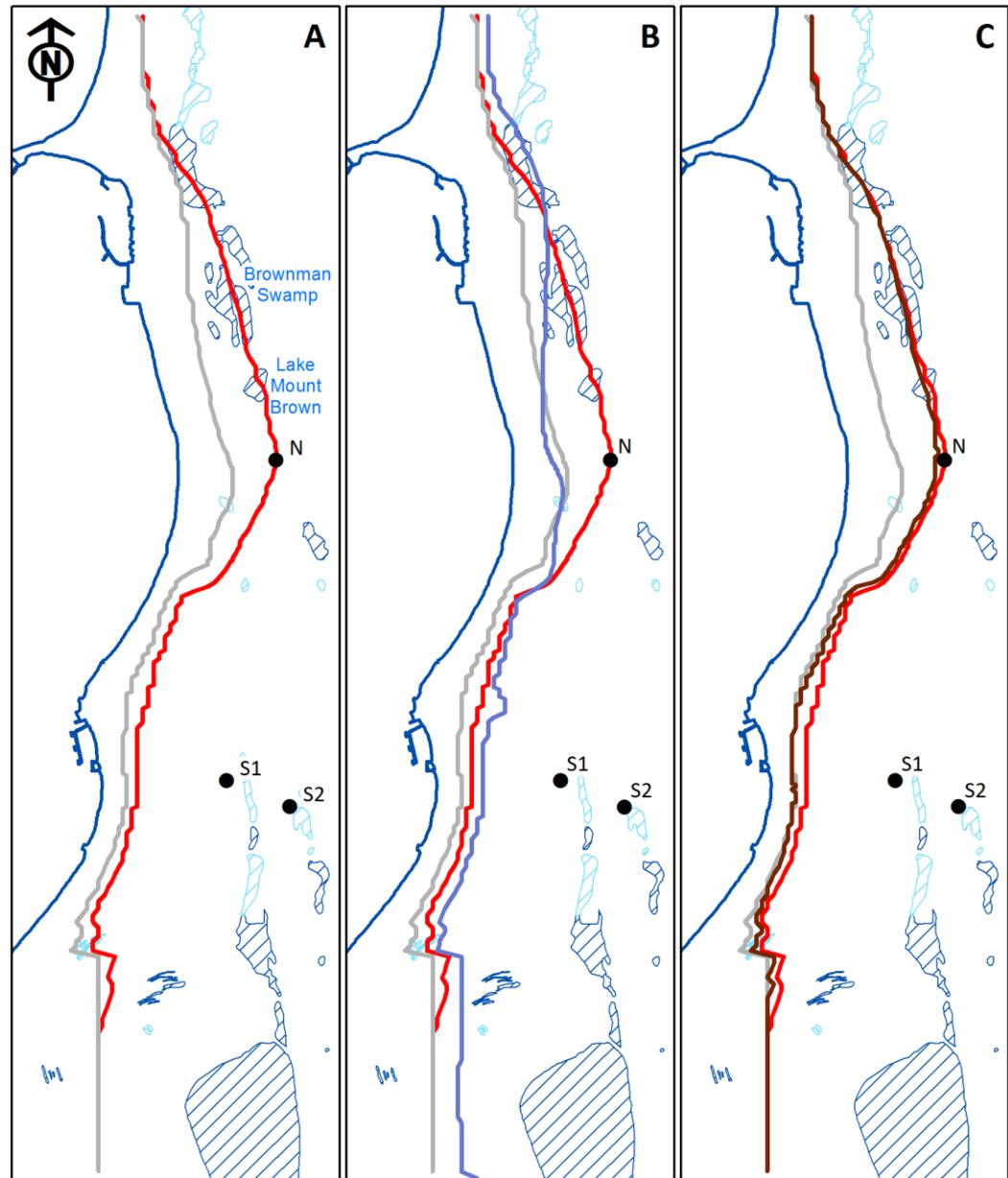
(IV) worst case (95th + no interception)



Seawater intrusion

Seawater interface calculated using Ghyben-Hertzberg approximation

- Business as usual
 - Advancement of SWI up to 0.92 km inland
- MAR able to maintain current position of SWI
 - Different responses depending upon hydrogeology



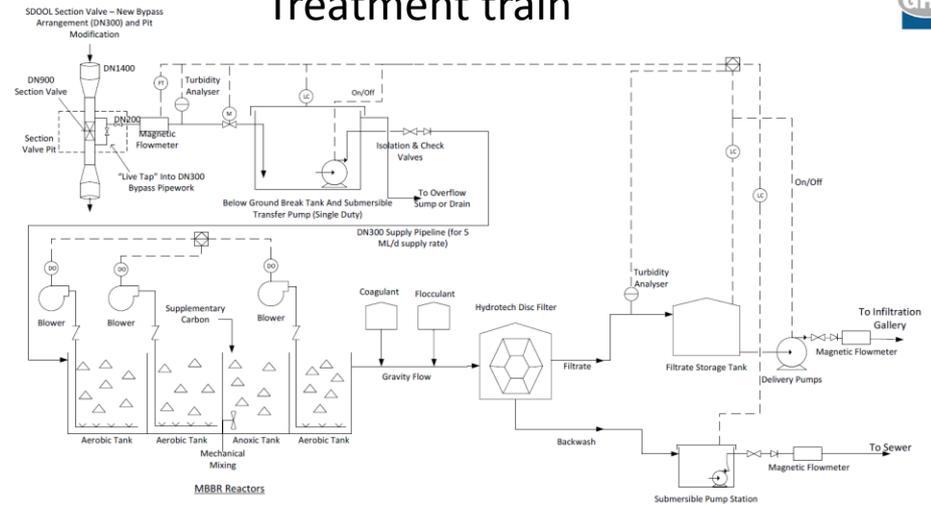
Engineering costings

CAPEX and OPEX estimates for:

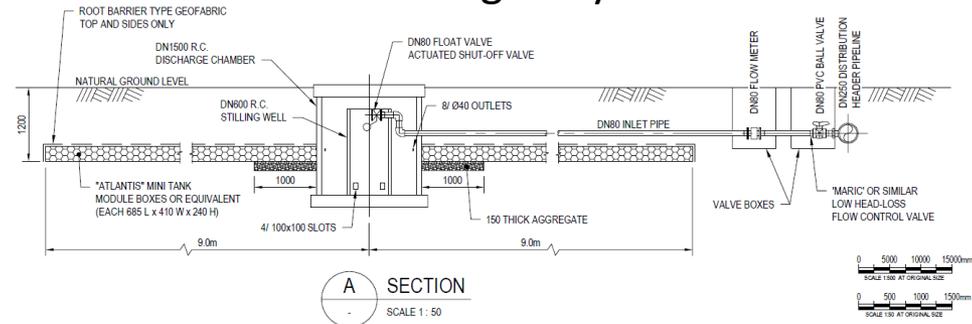
- TWW access and piping
- MAR infrastructure
 - Basins verses infiltration galleries
- Source dependent tertiary (pre-MAR) treatment
 - Suspended solid and nitrogen removal



Treatment train



Infiltration gallery cross-section



Economic Assessment – Benefit : cost ratio for site S2

Ratio = NPV of benefits ÷ NPV of cost

* High industrial demand; 7% interest rate, all MAR water able to be recovered; no charge for wastewater

INFILTRATION AND TREATMENT METHOD	4.8 ML/DAY
Option 1: Recharge basin	3.32
Option 2: Recharge basin (nitrogen & suspended solid reduction)	1.58
Option 3: Galleries (suspended solid reduction)	2.06
Option 4: Galleries (nitrogen & solid reduction)	1.43

Summary

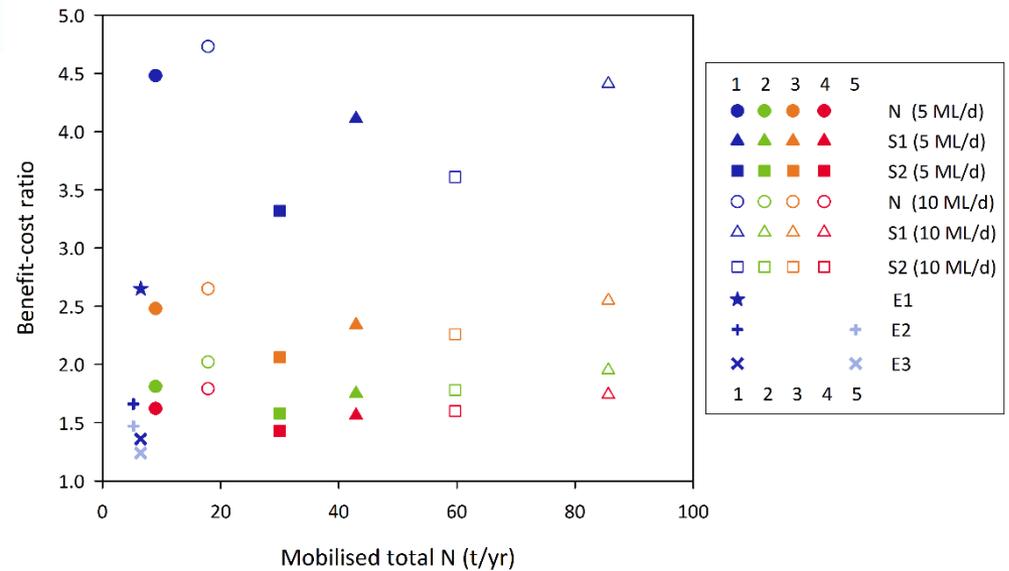
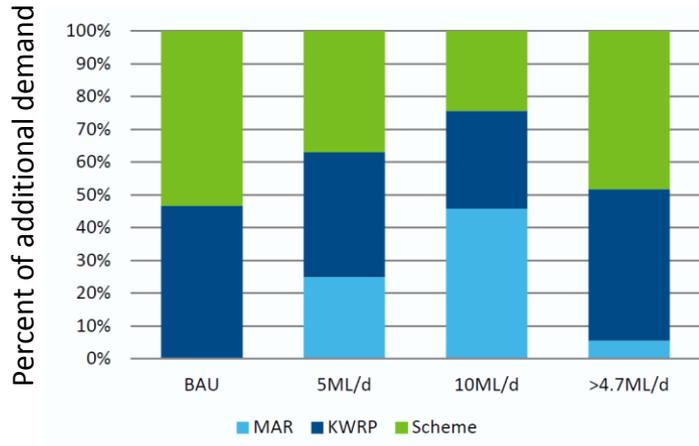
- Benefits > cost in all cases
- Basins > galleries
- Additional treatments reduced B:C
- 9.6 ML/d > 4.8 ML/d for all sites

Economic Assessment – Sensitivity analysis

Wastewater cost & recovery

SITE S2	LEVELISED COST OF MAR WATER (\$/kL)			MAR WATER RECOVERED			
	Treated Wastewater Price						
	@ \$0.5/kL	@ \$0.25/kL	@ \$0/kL	100%	80%	70%	60%
Recharge basin (no treatment)	1.02-1.12	0.77-0.87	0.52-0.62				
Recharge basin (nitrogen & suspended solid reduction)	1.56-1.80	1.31-1.55	1.06-1.30				X
Gallery (suspended solid reduction)	1.34-1.50	1.09-1.25	0.84-1.00				
Gallery (nitrogen & suspended solid reduction)	1.68-1.94	1.43-1.69	1.18-1.44				X
<i>KWRP water</i>	\$2.00 /kL						
<i>Scheme water</i>	\$2.093 /kL						

Economics and environmental impacts



Conclusions

- MAR is a viable option for meeting increasing industrial demand
- MAR was determined to be cost effective
 - Treatment, infiltration volume, TWW price and distance to access point impact MAR water price
- Impacts of MAR vary from site to site due to hydrogeological conditions
- Higher nutrient loads to Cockburn Sound is expected
 - However this can be managed through natural attenuation, groundwater capture and/or wastewater pre-treatment
- MAR may offset climate impacts on seawater intrusion and water sensitive ecosystems

Thank you

CSIRO Land and Water

Mike Donn

Senior Experimental Scientist

t +61 8 9333 6146

e michael.donn@csiro.au

w <https://research.csiro.au/mar/>

Acknowledgments

Don McFarlane (former CSIRO)

Elise Bekele (CSIRO)

Sorada Tapsuwan (CSIRO)

Irina Emelyanova (CSIRO)

Doug Edgar (GHD)

Roy Stone (DoW)

Alana French (DoW)

Warren Tierney (DoW)

Ursula Kretzer (DoW)

McFarlane DJ, Donn MJ, Bekele EB and Tapsuwan S (2015)
Recycled water for heavy industry and preventing sea water
intrusion. A report to the Australian Water Recycling Centre of
Excellence Government and industry partners from the CSIRO
Land and Water Flagship., Perth, Western Australia.
[https://publications.csiro.au/rpr/download?pid=csiro:EP155284&
dsid=DS2.](https://publications.csiro.au/rpr/download?pid=csiro:EP155284&dsid=DS2)

WGA

WALLBRIDGE GILBERT
AZTEC

MAR Technical Viability Assessment -

Will it work?

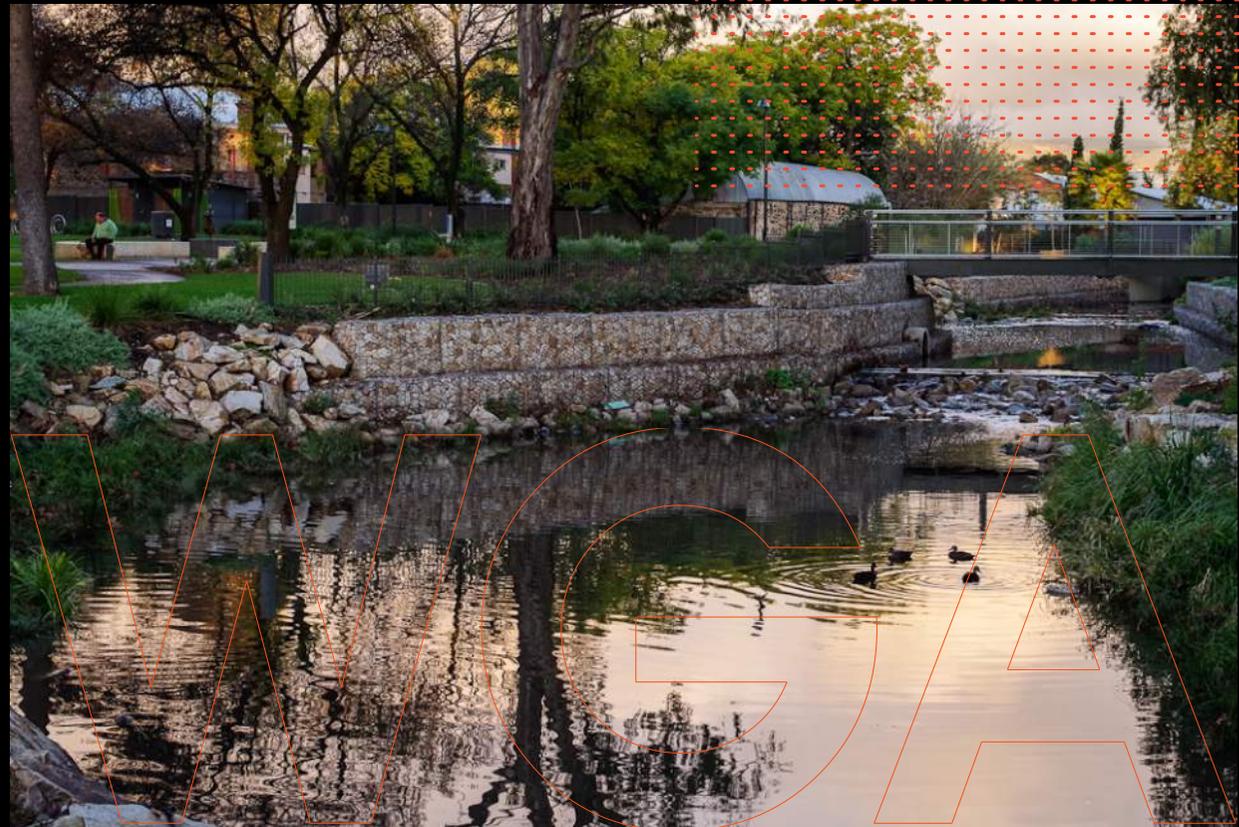
October 2017

RUSSELL MARTIN
Principal Hydrogeologist

rmartin@wga.com.au
ph +61 438 110 700

www.wga.com.au

45 minutes



Outline

1. Why MAR?
2. Types of MAR
3. MAR Objectives
4. Risk Assessment
5. Integration of Engineering & Hydrogeology
6. ASR Investigation Bores
7. Aquifer Characterisation
5. Economics
6. Policy



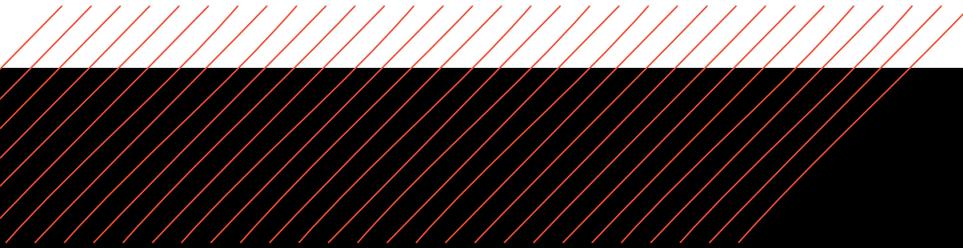
MAR Definition

Managed aquifer recharge is the purposeful recharge of an aquifer under controlled conditions to store the water for later abstraction or to achieve environmental benefits.

Potential sources of recharge water include:

- stormwater (excess or redirected),
- treated wastewater
- co-produced (associated water) from mining or petroleum activities.

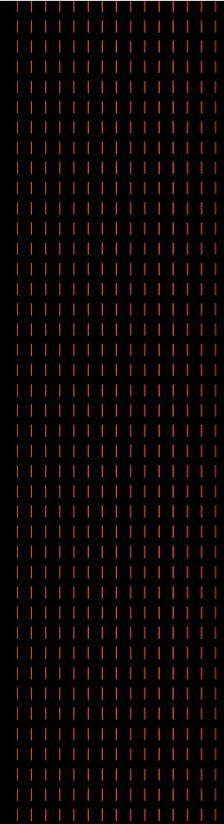
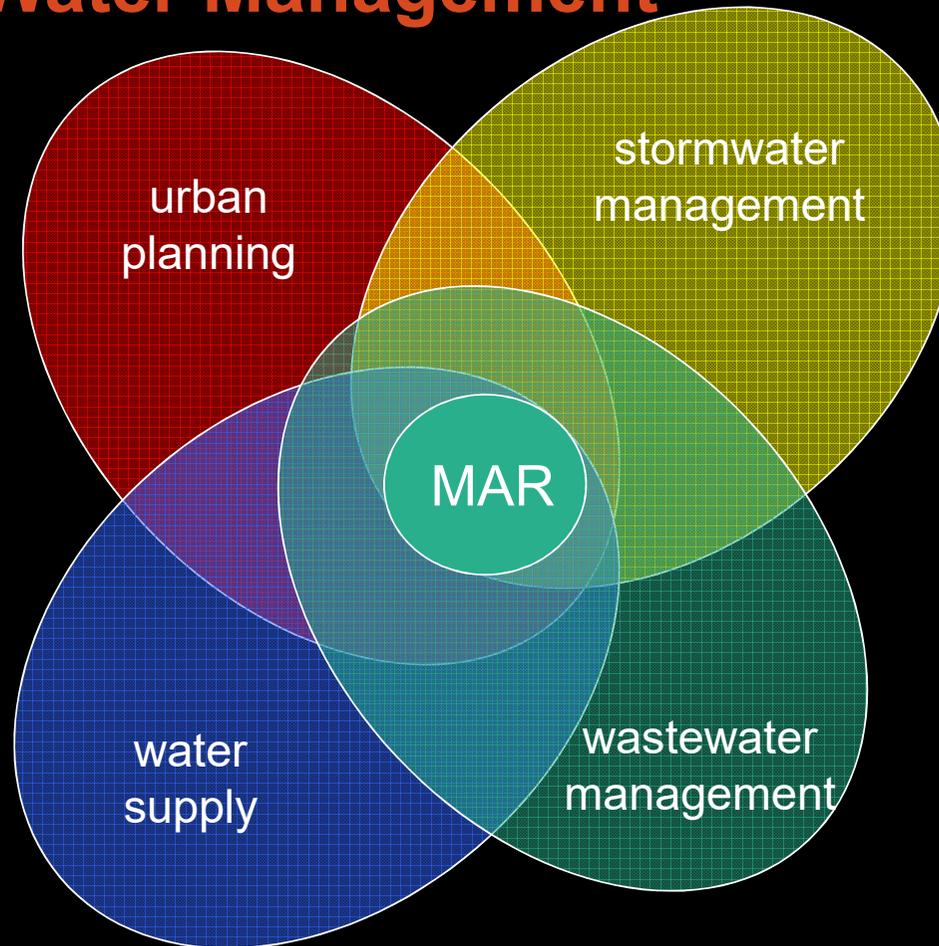




Why MAR?

- A tool to replenish aquifers and provide security of supply
- Generally the cheapest form of new water supply available.
- Can replenish depleted aquifers, protect groundwater-dependent ecosystems, defend against saline intrusion and land subsidence.
- Can help offset the costs of flood mitigation in urban catchments and of water reclamation costs where demand is out of balance with supply.

MAR Integrated Water Management

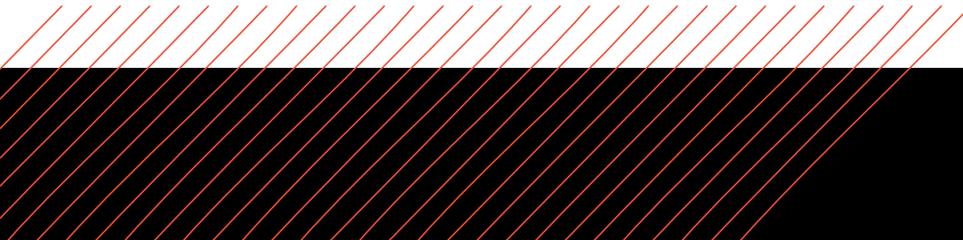


Several factors have contributed to global uptake of MAR

- **Economics**
 - Typically less than half the capital cost of alternative water supplies sources
 - Staged implementation
 - Marginal cost pricing
- **Proven success**
 - Knowledge over past 2 decades has increased tremendously
- **Environmental and Water Quality Benefits**
 - Maintain minimum flows
 - Water security
 - Liveability
 - Small storage footprint compared to surface reservoirs
- **Adaptability to Different situations**
 - Fresh, brackish or saline storage aquifers
 - Drinking water, reclaimed water, stormwater or groundwater storage.



Cooke Reserve – Waterproofing the West City of Charles Sturt



Advantages of aquifers compared to storage reservoirs

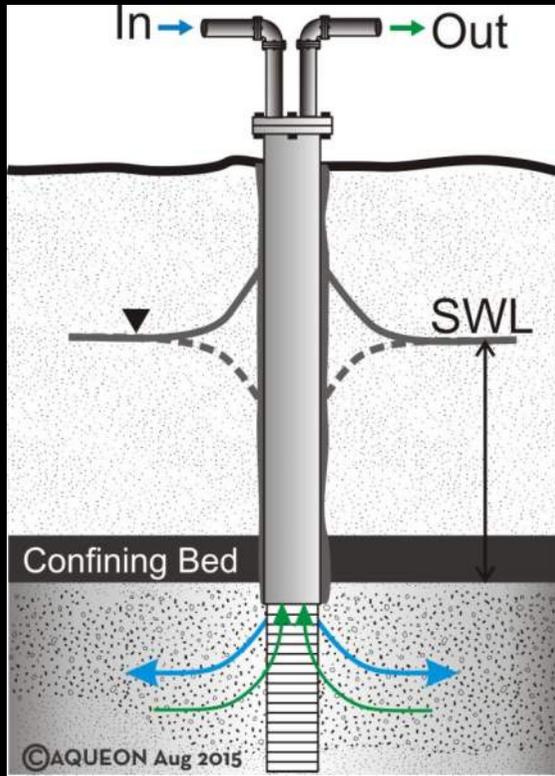
Advantages

- Smaller impact on above ground landuse especially in lowlands and built environs.
- Protection against algae blooms, fall out, evaporation loss.
- High natural attenuation (suspended solids, pathogens, TEs, OMPs, Rads, NO).
- Damping quality and temperature fluctuations.
- Lower cost than above ground storage of commensurate size
- Can be scaled up over time therefore capital costs can be spread out over time

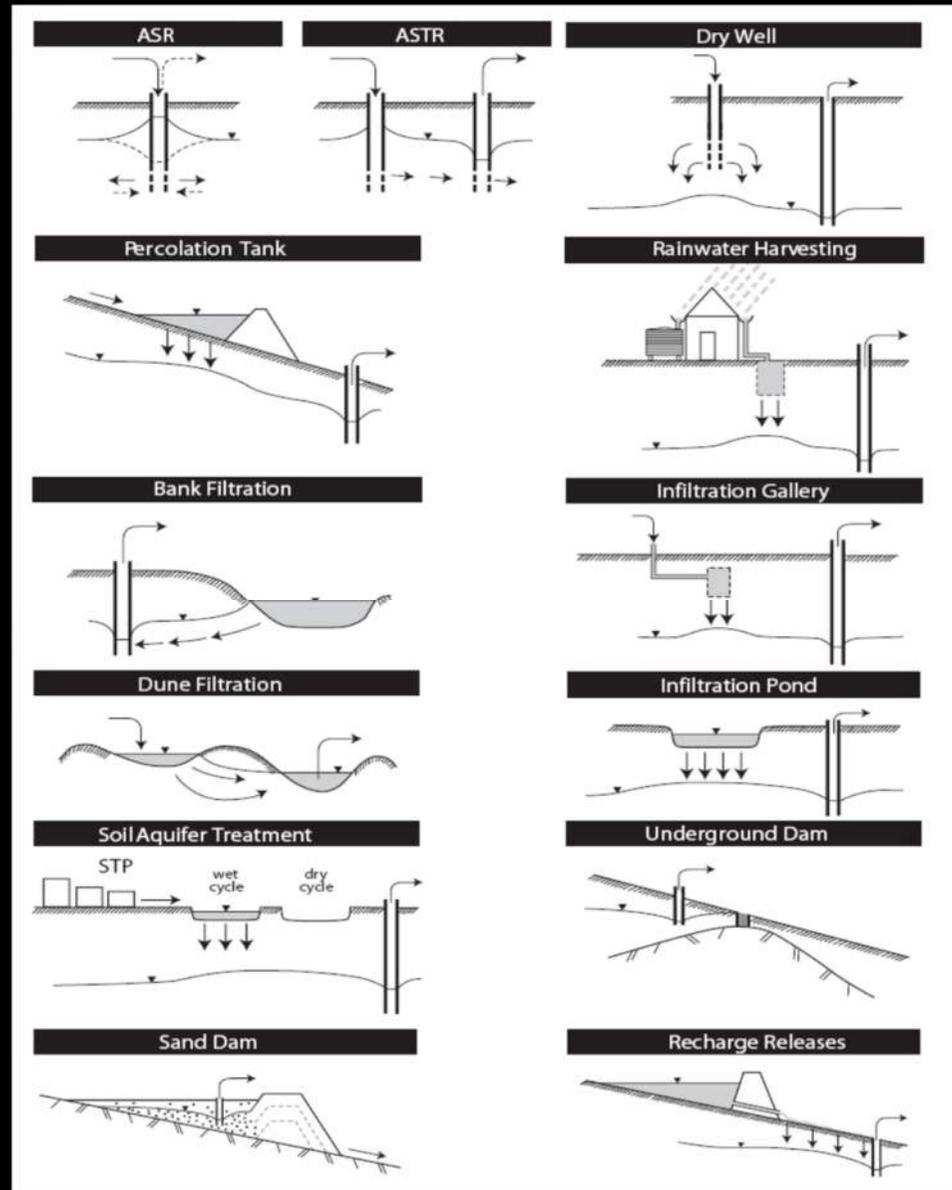
Problems

- Aquifers are not water tight (some water is lost Beyond capture zone, vertical leakage
- Surrounding saline groundwater may mix with injected water
- Reactions of water with aquifer matrix (Fe, Mn, NH₄, As ,Al)
- Infiltration / recovery rates can be limited by clogging of basins / wells / drains
- Need a suitable aquifer system
- Potentially higher level of O&M compared to above ground storage.

Types of MAR



Aquifer Storage & Recovery (ASR)



Select & Prioritise MAR Objective

(28 identified to date)

- Seasonal storage and recovery of water
- Long-term storage, or “water banking”
- Emergency storage, or “Strategic Water Reserve”
- Defer expansion of water treatment/ transmission facilities
- Disinfection byproduct (DBP) reduction
- Restore groundwater levels
- Maintain distribution system pressure and/or flow
- Prevent saltwater intrusion or aquifer contamination
- Maintenance or restoration of river flows, aquatic ecosystems and lake levels
- Reclaimed water storage for reuse and aquifer recharge
- Aquifer thermal energy storage (ATES, BTES)
- Agricultural water supply and nutrient reduction in runoff

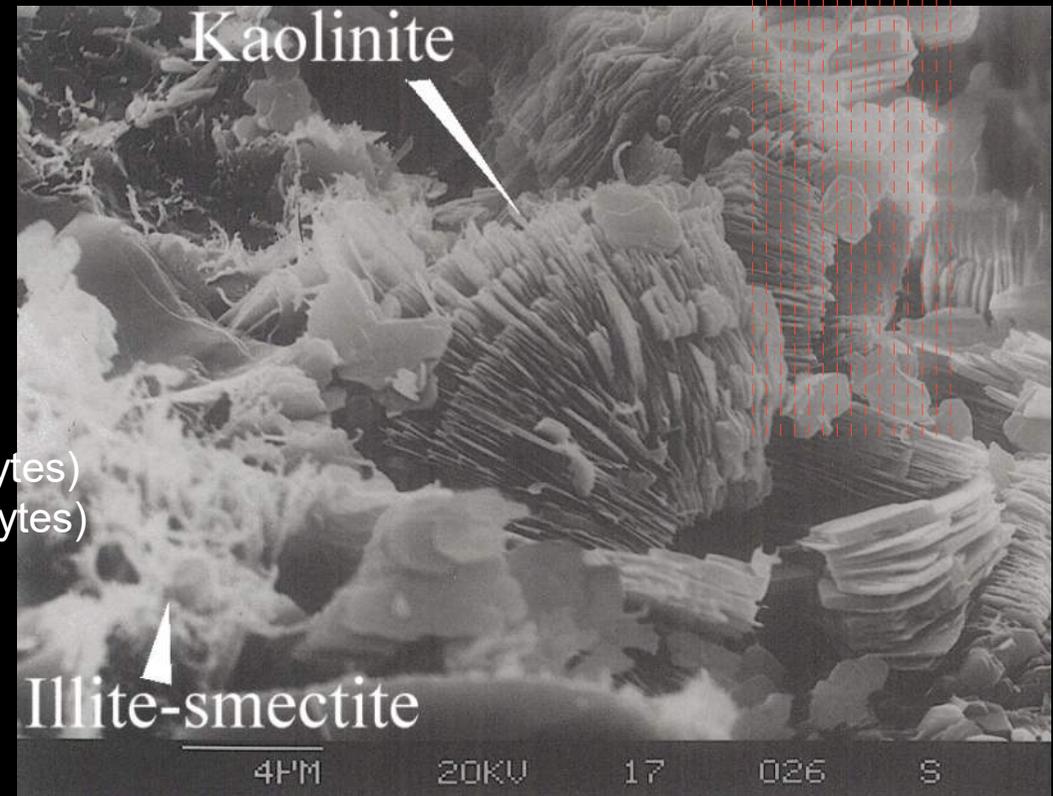


MAR System



Hydrogeological setting dictates the MAR type

- Aquifer characterization critical to the success of MAR system
- Tests include:
 - Geophysical logging
 - Aquifer discharge pumping tests
 - Sieve analysis
 - Coring
 - Column studies
 - Cation Exchange Capacity
 - XRD, XRF and SEM
 - Membrane filtration index (source water)
 - Water quality analysis groundwater (>120 analytes)
 - Water quality analysis source water (>120 analytes)



Conduct an MAR Feasibility Assessment

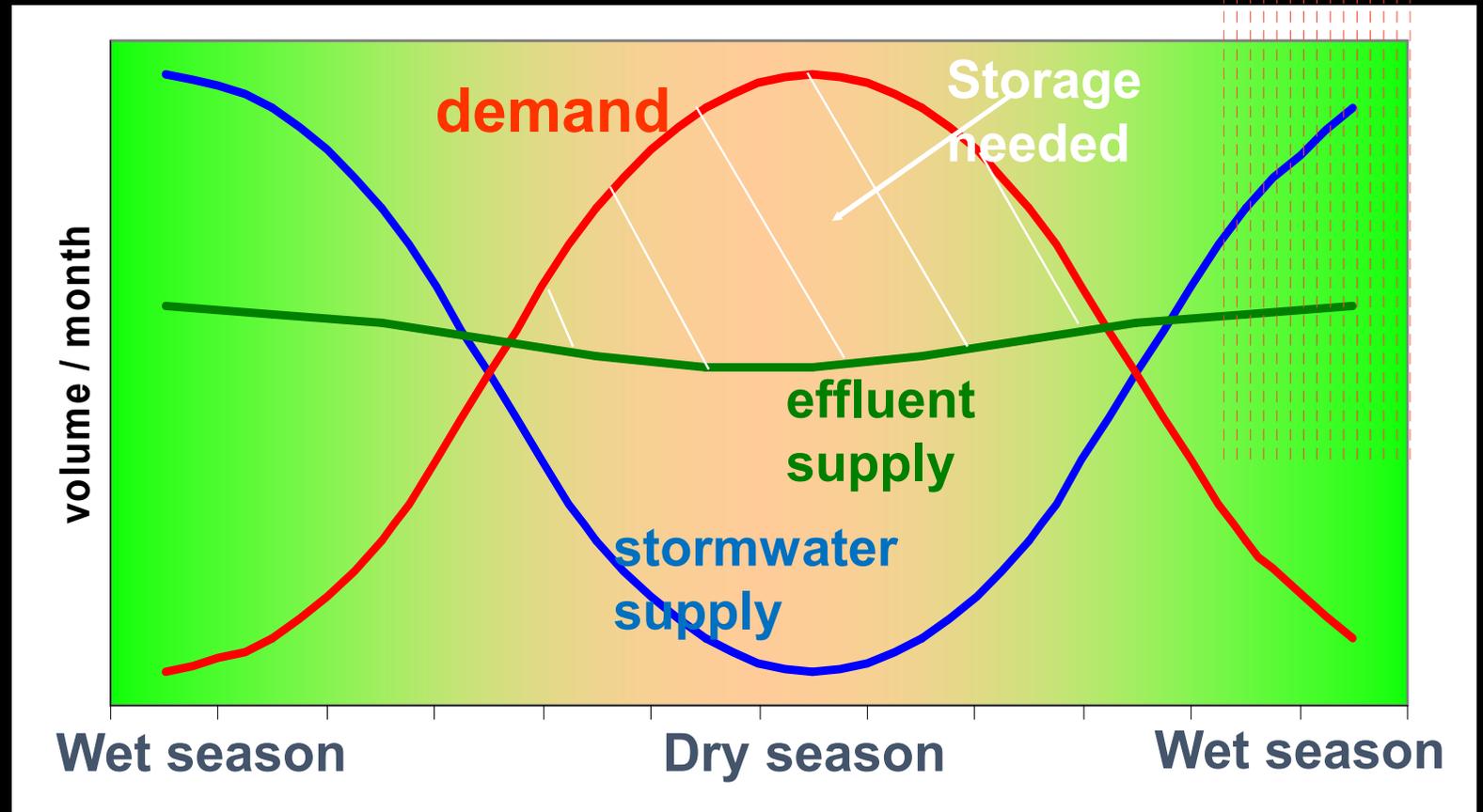
- Identify/ prioritize project objectives
- Water supply, trends and variability
- Water quality, trends and variability
- Water demand, trends and variability
- Risk assessment
- Target Storage Volume (TSV) requirements
- Hydrogeology and Geochemistry
- Selection of recharge process (ASR or surface)
- Selection of site(s)
- Conceptual design of well and wellfield facilities
- Preliminary capital and operating cost estimates
- Outline of planned cycle testing program
- Legal, regulatory and water rights issues
- Environmental considerations
- Institutional constraints
- Final report



Unity Park Wetland – City of Salisbury

Water supply trends and variability

- Storage is needed if demand exceeds supply at any time



MAR Risk Assessments

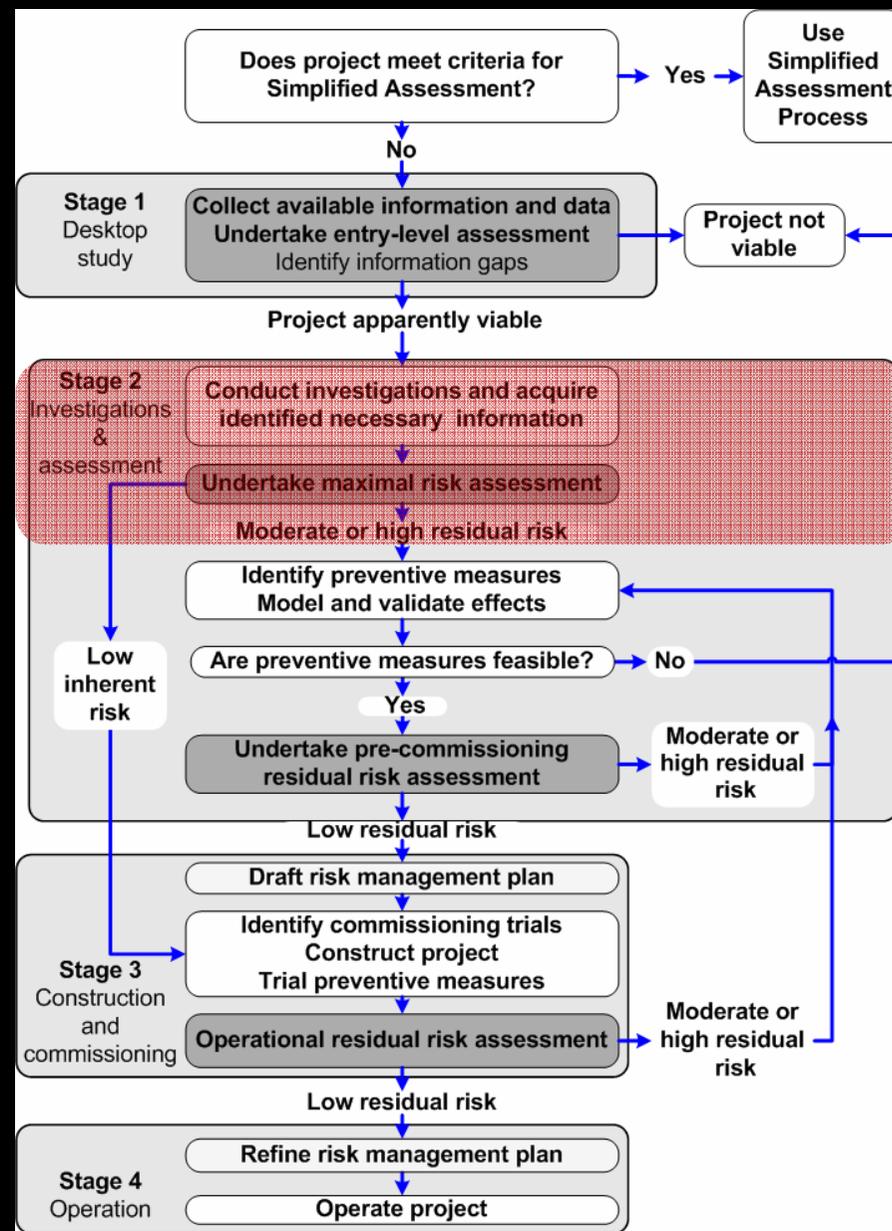
Twelve hazards to human health or the environment:

1. Pathogens
2. Inorganic chemicals
3. Salinity and sodicity
4. Nutrients
5. Organic chemicals
6. Turbidity and particulates
7. Radionuclides
8. Pressure, flow rates, volumes and levels
9. Contaminant migration in fractured rock and karstic aquifers
10. Aquifer dissolution and aquitard and well stability
11. Impacts on groundwater-dependent ecosystems
12. Greenhouse gases



Risk assessment stages in MAR project development

- Stage 1 Maximal risk assessment



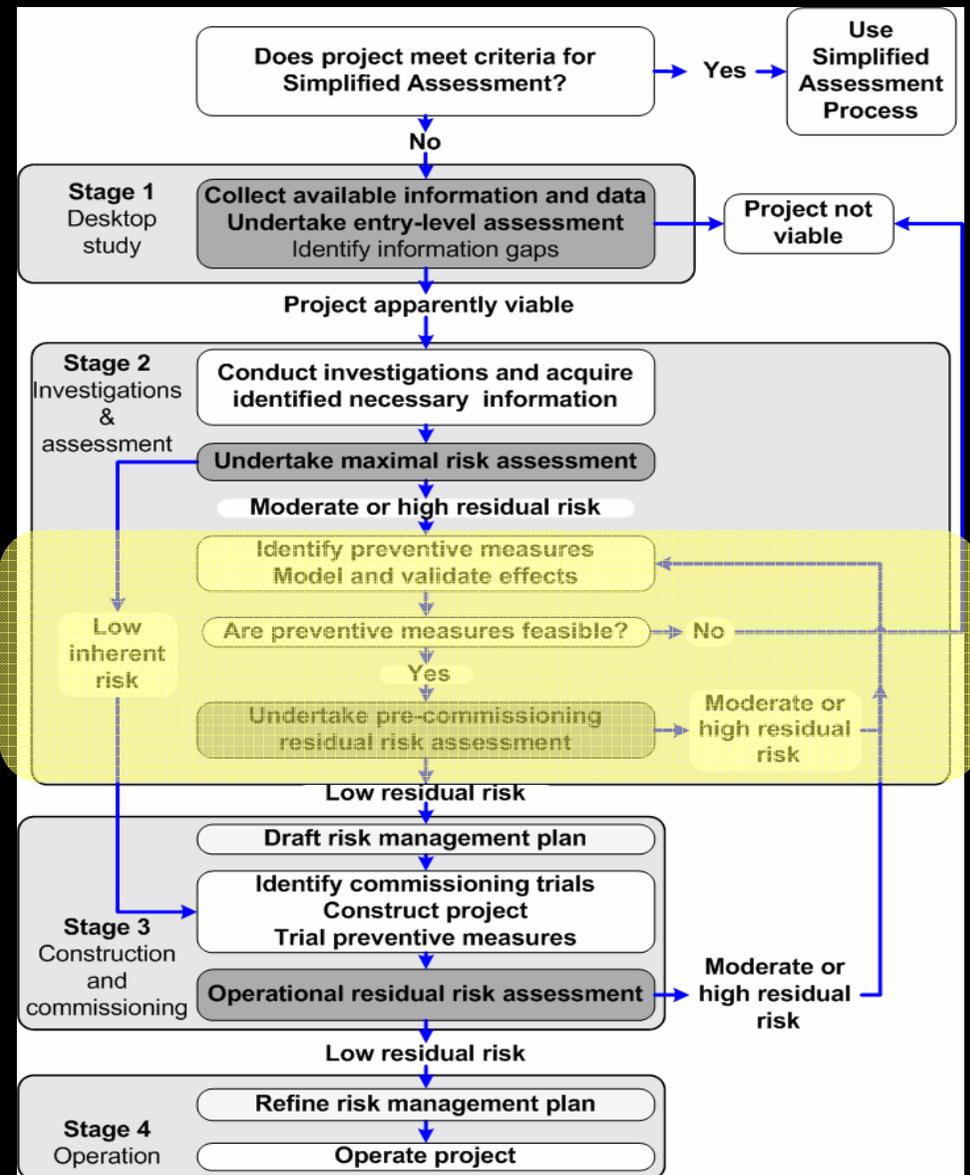
from MAR Guidelines, 2009

Maximal risk assessment

MAR Hazards		Human endpoint – ingestion of sprays	Environmental endpoint – green space irrigation	Environmental endpoint – aquifer
1.	Pathogens – pathogens present in untreated storm water	H	L	L
2.	Inorganic chemicals – none likely present at levels of concern for irrigation	L	L	L
3.	Salinity and sodicity – potential for mixing with native groundwater if not managed appropriately	L	U	L
4.	Nutrients: nitrogen, phosphorous and organic carbon – none likely present at levels of concern for irrigation	L	L	L
5.	Organic chemicals – none likely present at levels of concern for irrigation	L	L	L
6.	Turbidity and particulates – none likely present at levels of concern for irrigation	L	L	L
7.	Radionuclides- none likely present at levels of concern for irrigation	L	L	L
8.	Pressure, flow rates, volumes and groundwater levels – potential for artesian wells			U
9.	Contaminant migration in fractured rock and karstic aquifers – potential for karstic features unknown			U
10.	Aquifer dissolution and stability of well and aquitard – aquifer and well stability unknown			U
11.	Aquifer and groundwater-dependent ecosystems – none present in the target aquifer which is saline and anoxic			L
12.	Energy and greenhouse gas considerations – unknown compared to other options			U

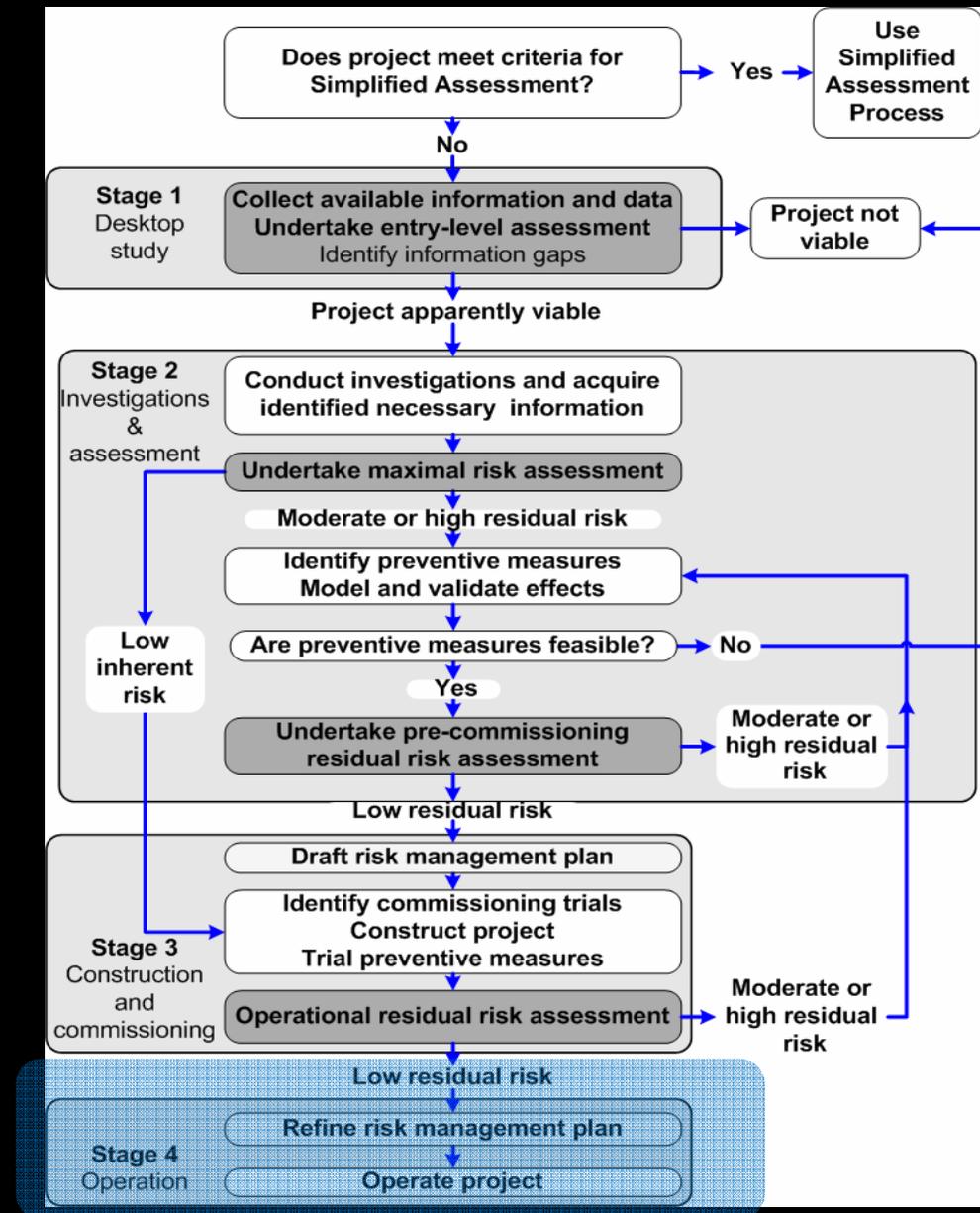
Stage 2 Residual risk assessment

- Identify preventative measures based on risk:
 - For the human health risk from pathogens the aquifer treatment step to remove pathogens will need to be validated.
 - Minimising exposure to recovered water by irrigating only at night is another potential preventative measure for pathogen risks.
 - For the salinity risks, mixing and control of recovery efficiency is required for the protection of plants receiving irrigation water.



Stage 4 Risk assessment

- Refine risk management plan based on the Operational residual risk assessment.
- Define verification monitoring program to confirm that the plan is working as it should.
- Revise and update plan periodically with data collected on site to ensure that the risks are controlled.



Aquifer characteristics favouring ASR

Characteristic	Usually favourable	Usually unfavourable	Reason
Permeability	High	Low	storage
Thickness * porosity	High	Low	storage
Uniformity of hydraulic properties	Uniform	Heterogeneous	recovery
Ambient lateral hydraulic gradient	Gentle	Steep	recovery
Salinity of native g/w	Fresh	Saline	recovery
Degree of consolidation	High	Low	clogging
Unreactive minerals	Unreactive	Reactive	WQ & clogging
Confinement	Confined	Unconfined	WQ & recovery
Temperature	Warm	Cool	WQ & clogging

Subsurface characteristics favouring infiltration systems

Characteristic	Usually favourable	Usually unfavourable	Reason
Permeability	High	Low	storage
Thickness * porosity	High	Low	storage
Uniformity of hydraulic properties	Uniform	Heterogeneous	recovery
Ambient lateral hydraulic gradient	Gentle	Steep	recovery
Salinity of native g/w	Fresh	Saline	recovery
Degree of consolidation	High	Low	clogging
Unreactive minerals	Unreactive	Reactive	WQ & clogging
Confinement	Unconfined	Confined	access to aquifer for storage
Temperature	Warm	Cool	WQ & clogging

Aquifer attributes and in-situ water quality changes

Characteristic	Usually favourable	Usually unfavourable	Reason
Temperature	Warm	Cool	reaction rates
Pore size	Small	Large	reaction sites, straining
Presence of divalent cations	Present	Absent	enhances sorption and virus attachment
Minerals and organic matter capable of sorption	Present	Absent	sorption
Aerobic - anoxic	aerobic	anoxic	many exceptions, e.g. THMs, depends on source water contrast

Effective Integration of Engineering and Hydrogeology - 1

ENGINEERING

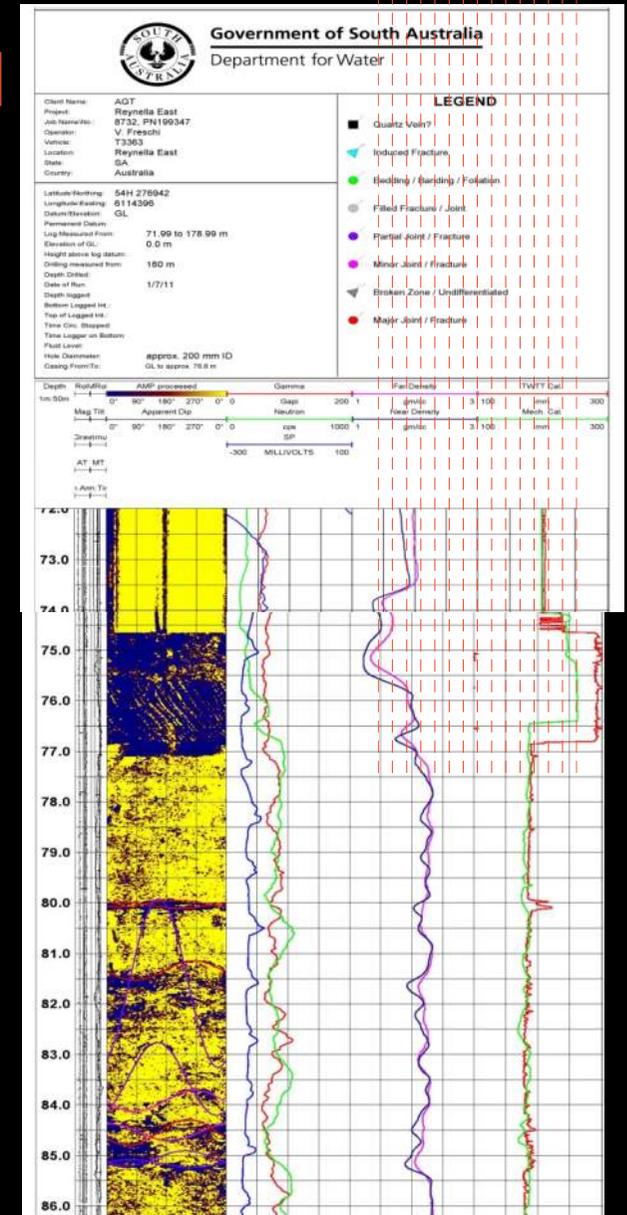
- Entrained and Dissolved Air Management
- Backflushing to Waste
- Pressure and Water Level Control
- Managing Variable Recharge and Recovery Flow Rates
- Trickle Flow
- Interim Recharge
- Electrical Design to Facilitate Well Redevelopment
- Downhole Flow Control
- Materials of Construction
- Monitoring of Flows, Volumes, Levels, Pressures, Quality
- Instrumentation and Control
- Operations



Effective Integration of Engineering and Hydrogeology - 2

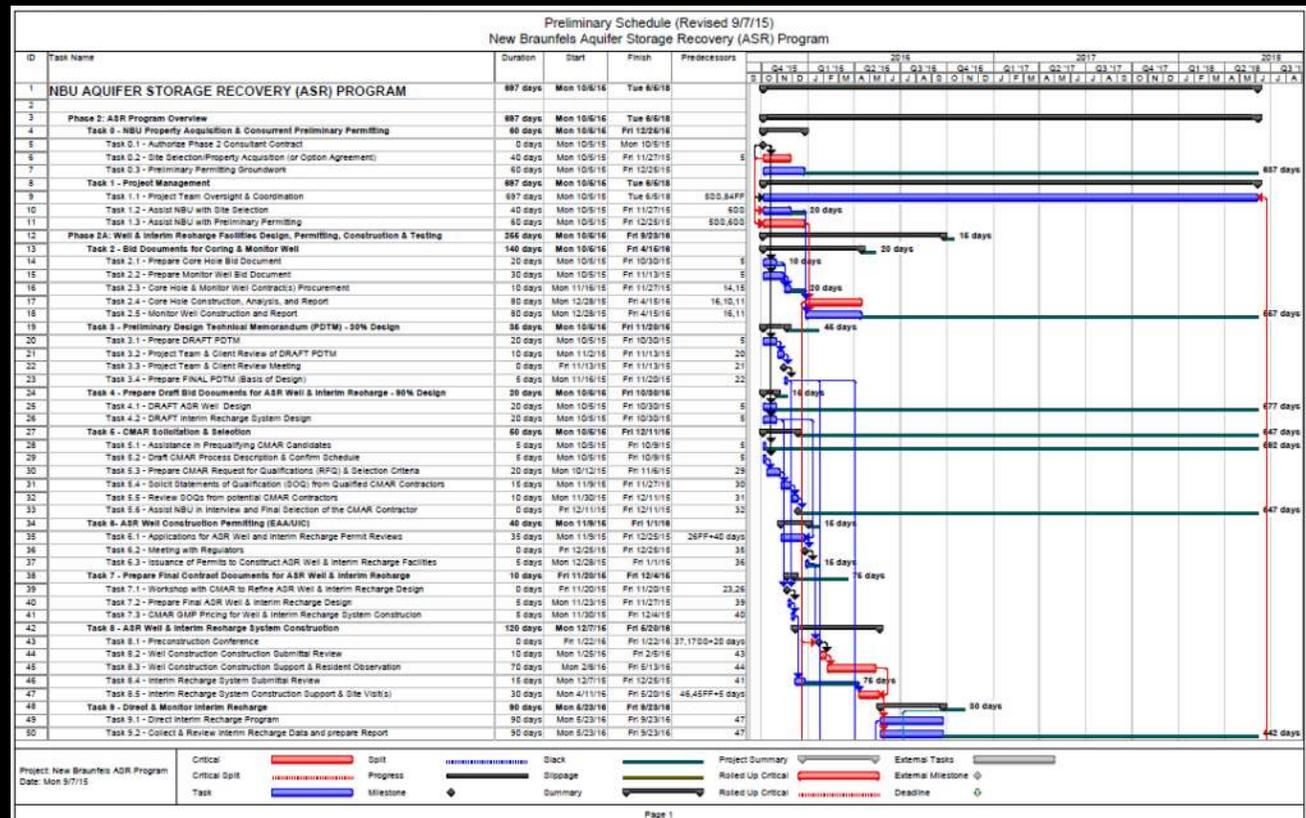
HYDROGEOLOGY

- Selection of Storage Aquifer
- Geology, Stratigraphy, Lithology
- Aquifer hydraulic characteristics
- Lateral Movement of Stored Water
- Well Spacing
- Coring, Core Analysis and Geochemical Analysis
- Wellfield Operation to Maximize Recovery Efficiency
- Well Development
- Monitor Wells
- ASR Geochemical Testing in a Storage Zone Monitor Well



Staging to Manage risk and Uncertainty

- Develop an MAR program in stages, incorporating data and experienced gained in each stage into the design and implementation of the next stage
- Review and audit of each stage by experienced practitioner



ASR investigation bores

- Drilling Method
 - Mud Rotary
 - Air / Hammer
 - Sonic
 - Need to take cores?
- Bore completion
 - Diameter
 - Screen selection
 - Production zone development
 - Production zone selection (single/multiple?)
 - Down hole flow control
 - Pump selection



Select appropriate materials for construction

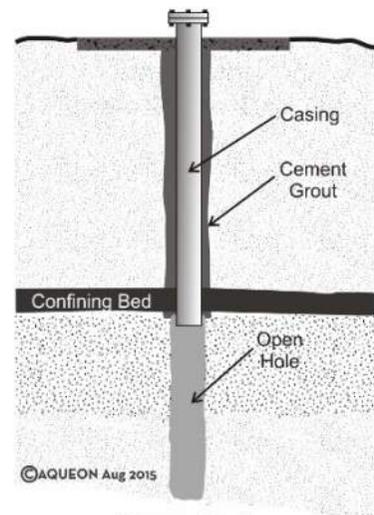
- Try to avoid carbon steel inner well casing
- Consider alternatives such as:
 - PVC
 - Fiberglass
 - 304 Stainless Steel
 - Epoxy-coated Carbon Steel
- Filter Pack
 - High quality Silica gravel
 - Spherical Glass Beads (“SiLibeads”)



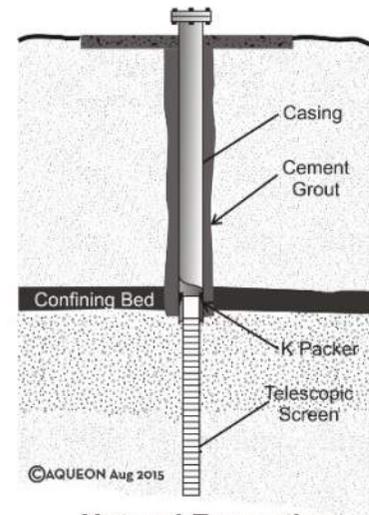
Fiberglass Reinforced Plastic (FRP) casing

Well completion

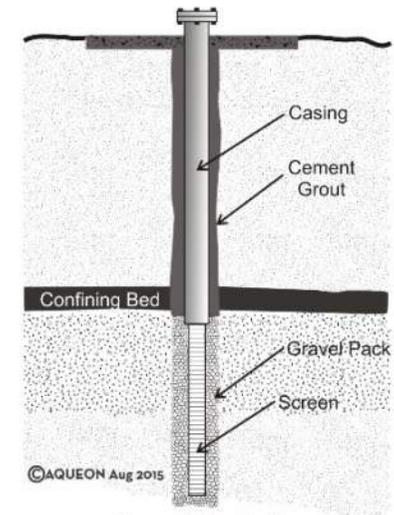
- In selecting completion method ask this fundamental question..
- *how am I going to remediate this bore when it clogs?*



Open Hole



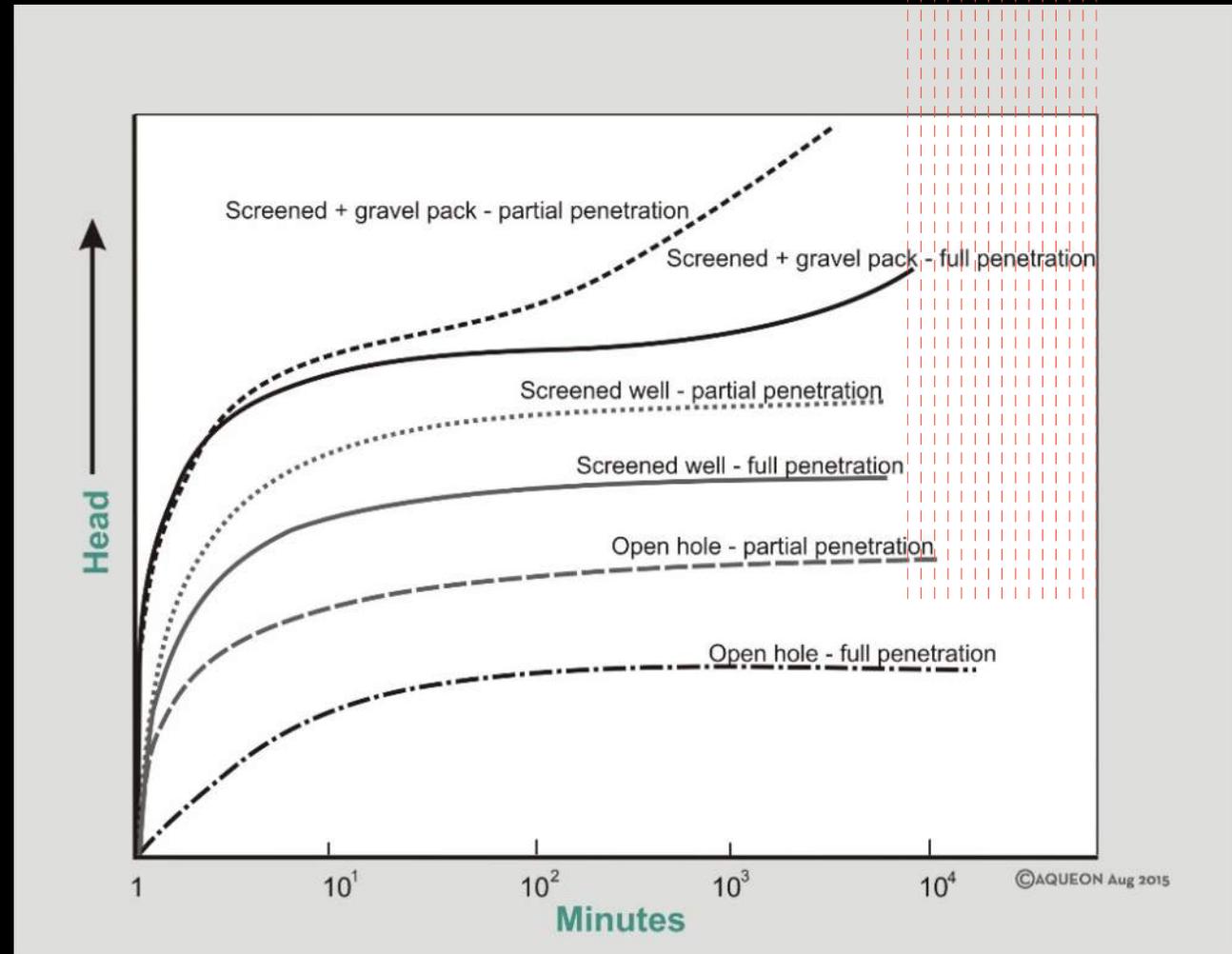
Natural Formation Pack



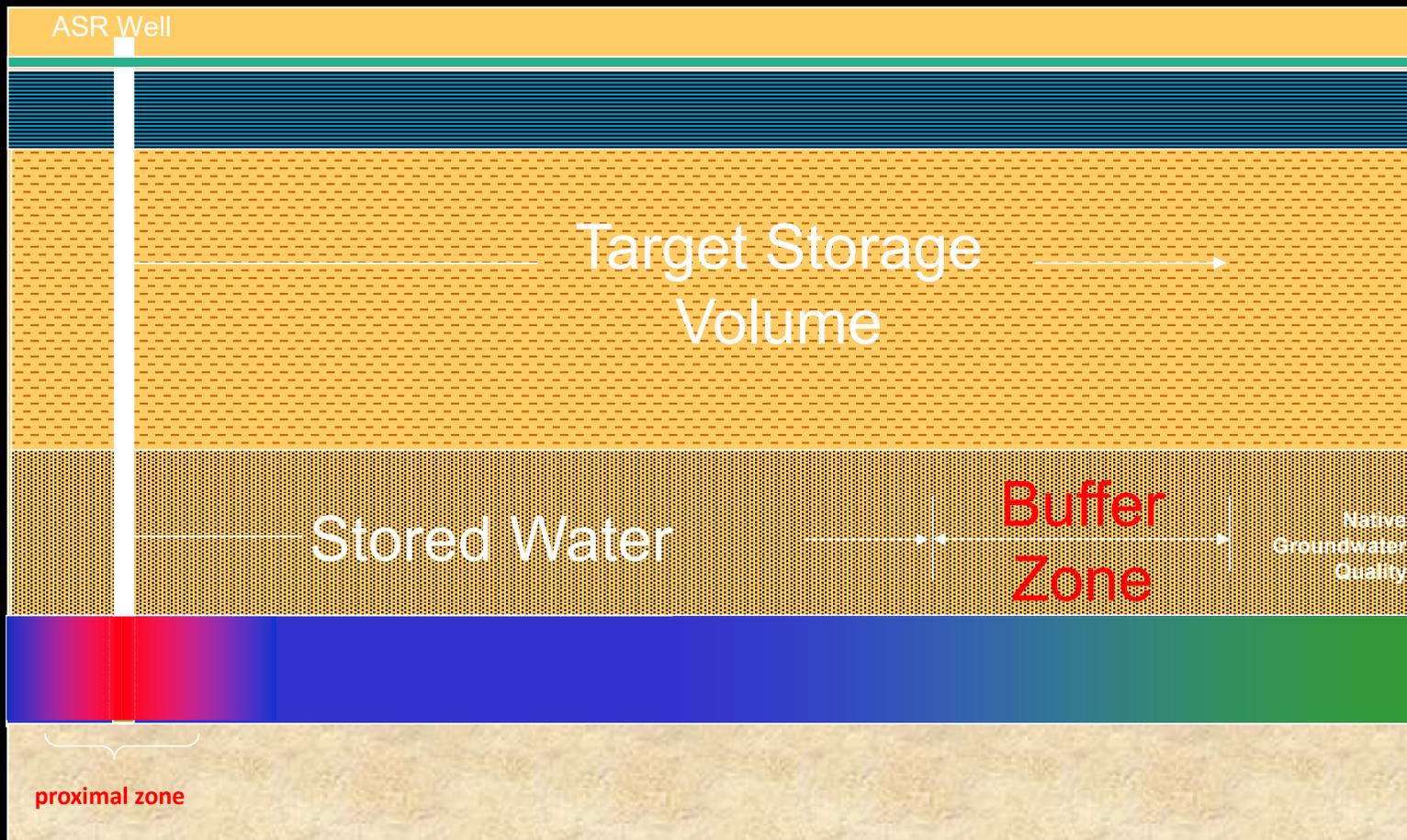
Gravel Pack & Screen

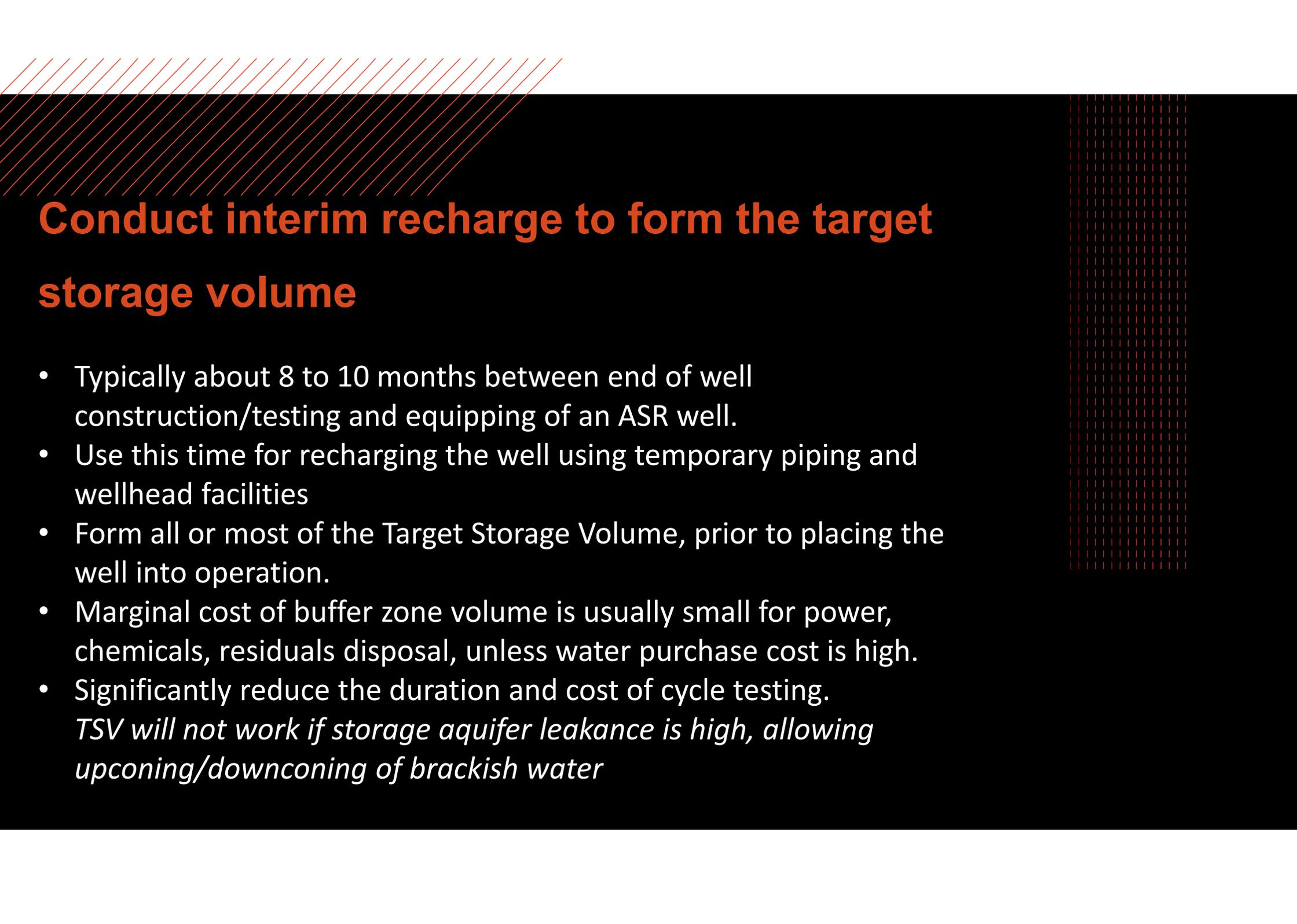
Injection efficiency

- Completion affects injection performance
- Completion also influences available remediation options in the event rehabilitation is required.



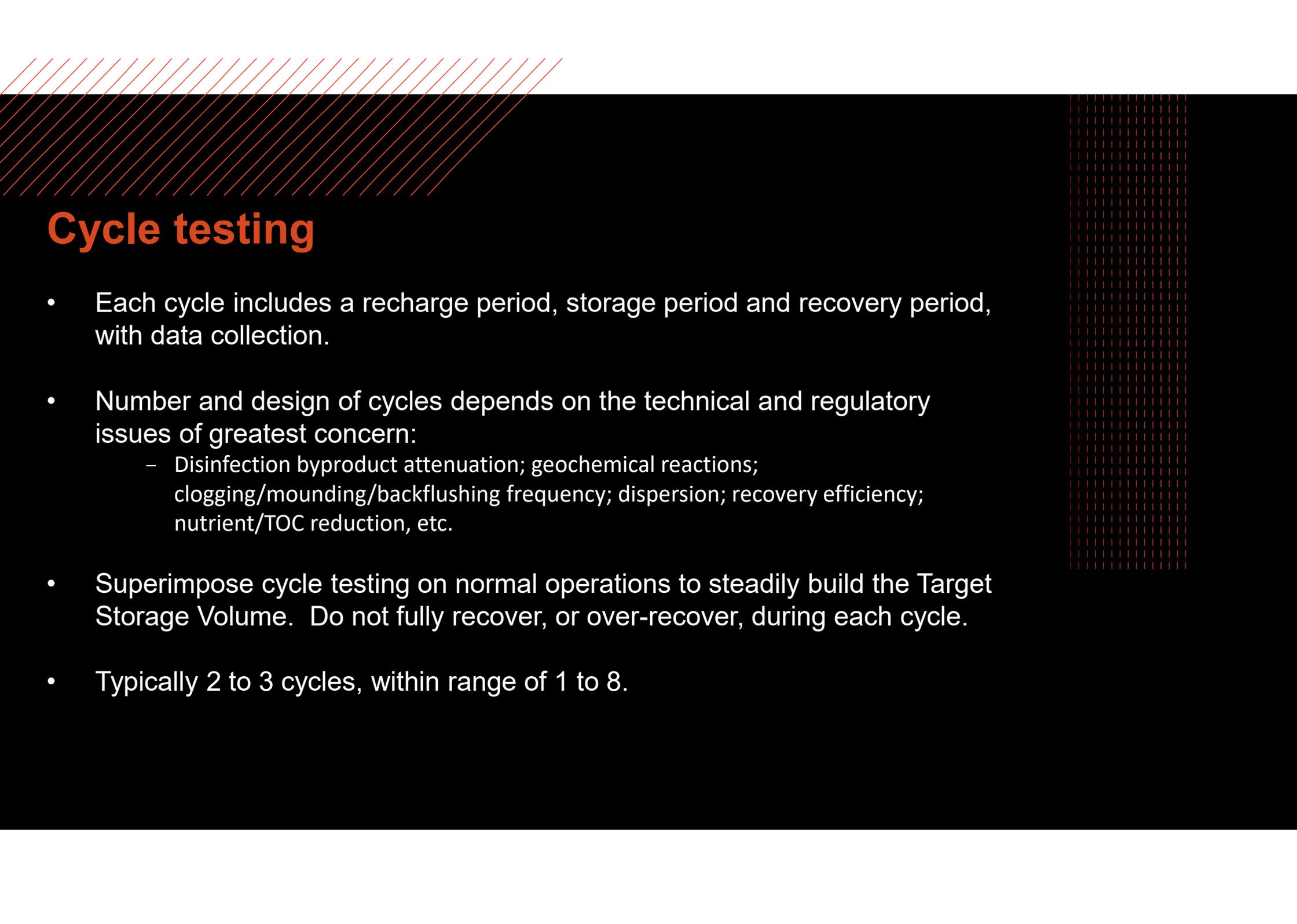
Form and maintain a Target Storage Volume (TSV)





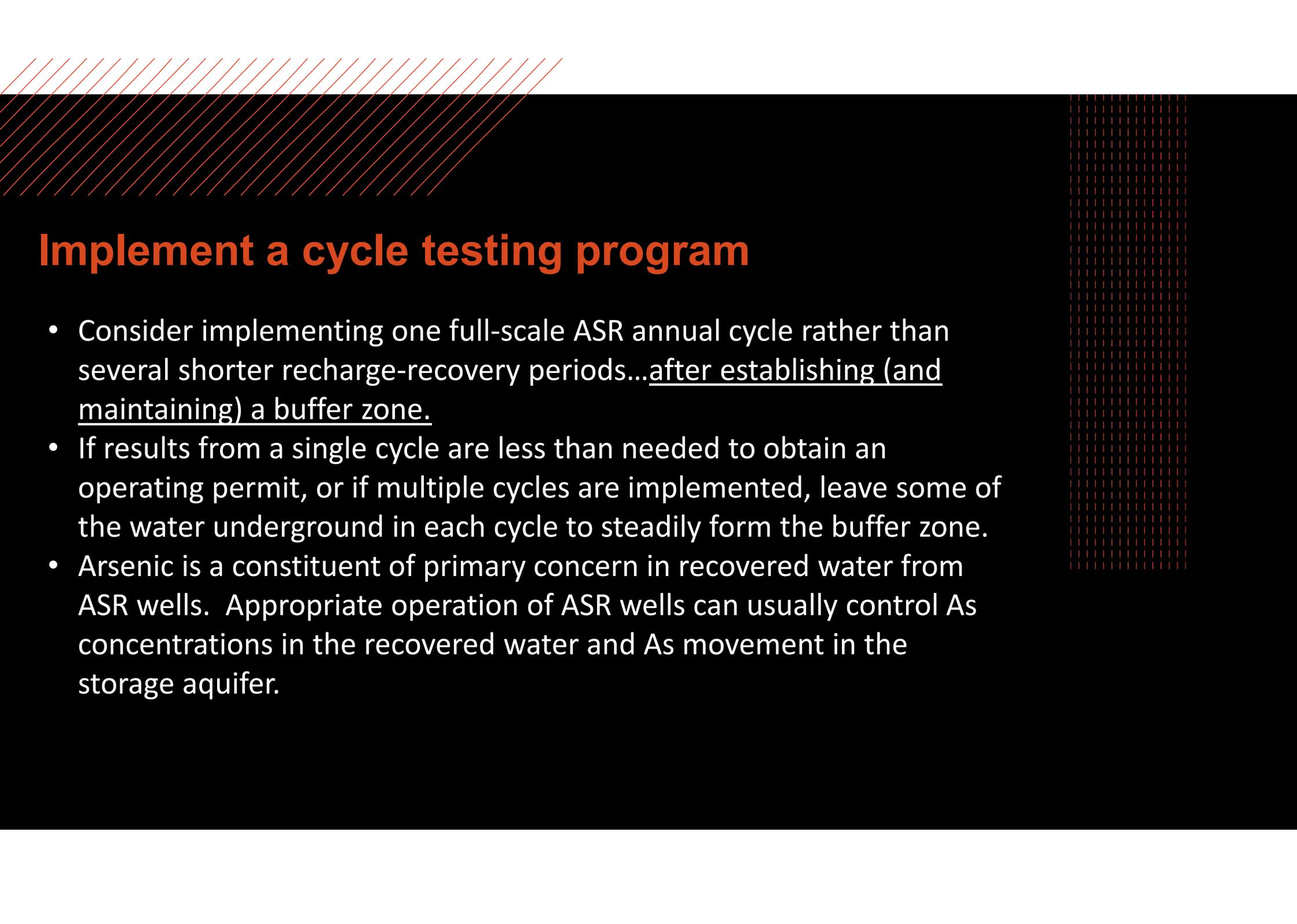
Conduct interim recharge to form the target storage volume

- Typically about 8 to 10 months between end of well construction/testing and equipping of an ASR well.
- Use this time for recharging the well using temporary piping and wellhead facilities
- Form all or most of the Target Storage Volume, prior to placing the well into operation.
- Marginal cost of buffer zone volume is usually small for power, chemicals, residuals disposal, unless water purchase cost is high.
- Significantly reduce the duration and cost of cycle testing.
TSV will not work if storage aquifer leakance is high, allowing upconing/downconing of brackish water



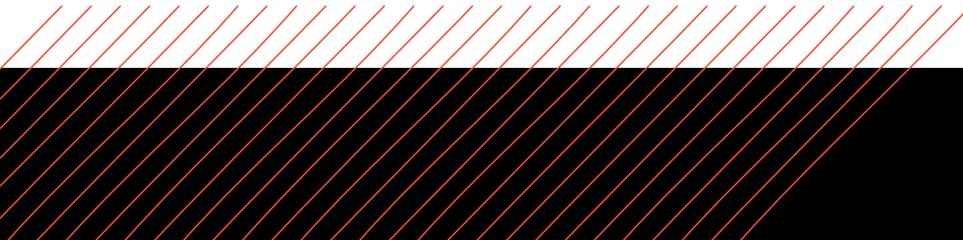
Cycle testing

- Each cycle includes a recharge period, storage period and recovery period, with data collection.
- Number and design of cycles depends on the technical and regulatory issues of greatest concern:
 - Disinfection byproduct attenuation; geochemical reactions; clogging/mounding/backflushing frequency; dispersion; recovery efficiency; nutrient/TOC reduction, etc.
- Superimpose cycle testing on normal operations to steadily build the Target Storage Volume. Do not fully recover, or over-recover, during each cycle.
- Typically 2 to 3 cycles, within range of 1 to 8.



Implement a cycle testing program

- Consider implementing one full-scale ASR annual cycle rather than several shorter recharge-recovery periods...after establishing (and maintaining) a buffer zone.
- If results from a single cycle are less than needed to obtain an operating permit, or if multiple cycles are implemented, leave some of the water underground in each cycle to steadily form the buffer zone.
- Arsenic is a constituent of primary concern in recovered water from ASR wells. Appropriate operation of ASR wells can usually control As concentrations in the recovered water and As movement in the storage aquifer.



Conduct geochemistry investigations and monitoring

- Evaluate geochemical risk at selected ASR site during ASR feasibility study
- Consider whether to obtain continuous wireline cores
 - Core lab analysis
 - Geochemical modeling of storage zone lithology and mineralogy, native water quality and recharge water quality
- Consider whether to confirm geochemical model results with field geochemical testing in a storage zone monitor well
- Confirm geochemical response during cycle testing, making treatment and/or buffer zone adjustments as necessary

ASR training and operations

- ASR Operator Training is Essential
 - Draft and Final O&M Manual
 - Hands-on Training
 - Data Collection and Evaluation (Hydraulic, W. Quality)
 - Periodic (annual) data review and recommendations for operational adjustments
 - Monitoring requirements adjusted, as appropriate
- Operations Staff Turnover and Basic Re-Training
- ASR Well Redevelopment (RISD)



Conclusions

- ASR is proven, very cost-effective, and has many different applications to achieve water supply goals.
- Storing large volumes of water underground is gaining acceptance as a relatively low cost solution to meeting many water management needs, supplementing other water supply and storage options.
- ASR solutions are targeting ever larger (regional, national) water management issues.
- ASR can help to meet global water supply goals with high reliability and sustainability



Conclusions

- MAR is a collection of widely used technologies for water supply and water security, and water quality protection.
- It can greatly improve efficiency of water management and is often the cheapest form of water storage.
- Whether it can be used and which form of use will depend on the aquifers available.
- Investigations are required for every new site to assess viability.
- Several key factors help to ensure ASR success.
 - Aquifer characterization
 - Understanding demand and supply
 - Clearly defined priorities for implementing MAR



WGA

WALLBRIDGE GILBERT
AZTEC

Questions

ADELAIDE

60 Wyatt Street
South Australia 5000
Telephone: +61 8 8223 7433

WALLBRIDGE GILBERT AZTEC

www.wga.com.au





MINDEROO

Viability of enhanced borefield recharge using an upside-down weir on the Ashburton River

Presenter: Don Scott, Pennington Scott

MAR Essentials Workshop

National Centre for Groundwater Research and training (NCGRT) and
International Centre for Excellence in Water resources Management (ICEWaRM)

1.15 – 1.45 on Thursday 26th
Mercure Hotel Perth

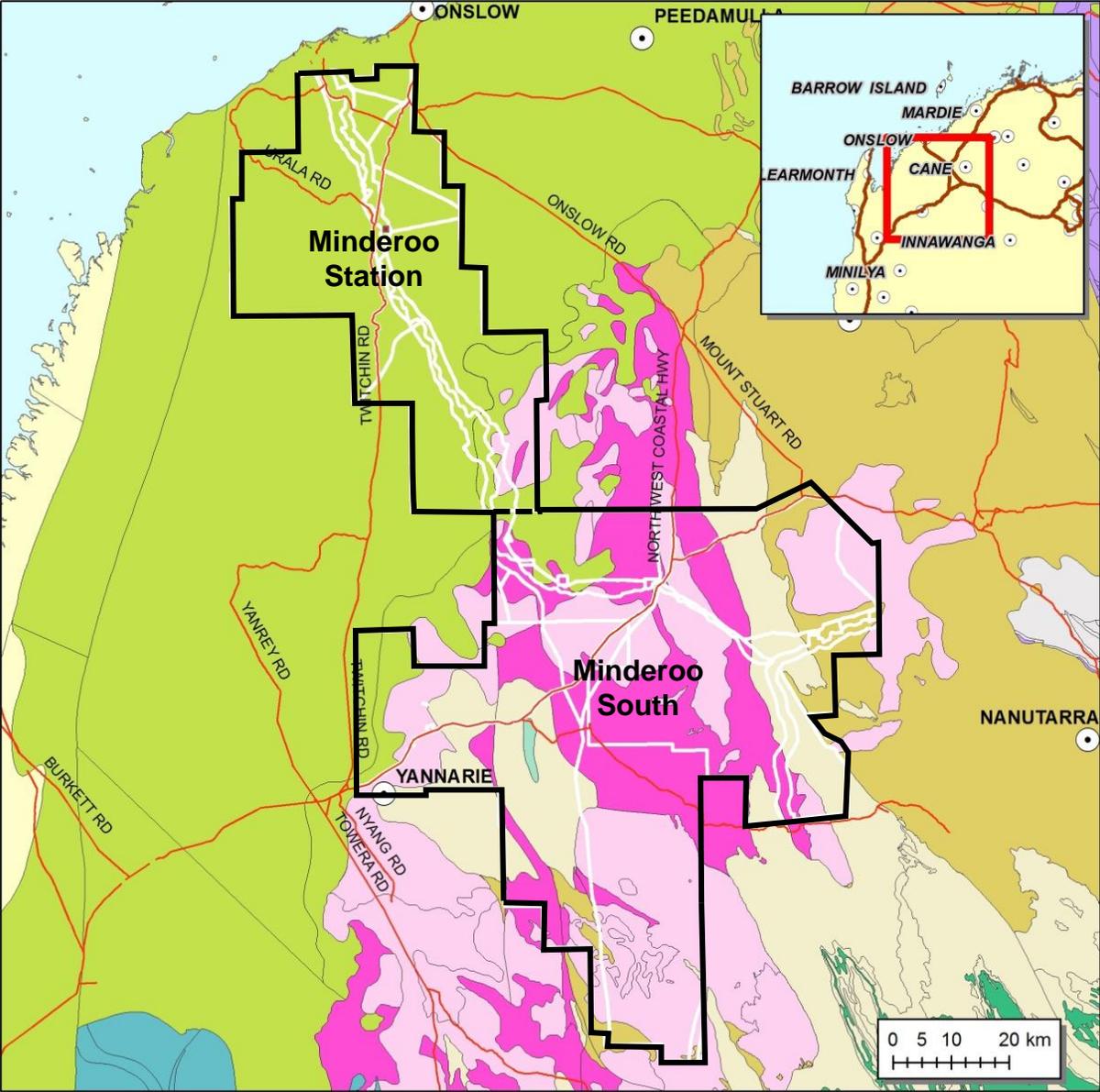


DROUGHT PROOFING MINDEROO

Apart from a brief period between 1998-2009, Minderoo has been Forrester hands since 1878



Minderoo Homestead, 2013



DROUGHT PROOFING MINDEROO

Apart from a brief period between 1998-2009, Minderoo has been Forrest hands since 1878

Stocks **11,000 head** of cattle in good years.



Droughtmaster cattle

DROUGHT PROOFING MINDEROO

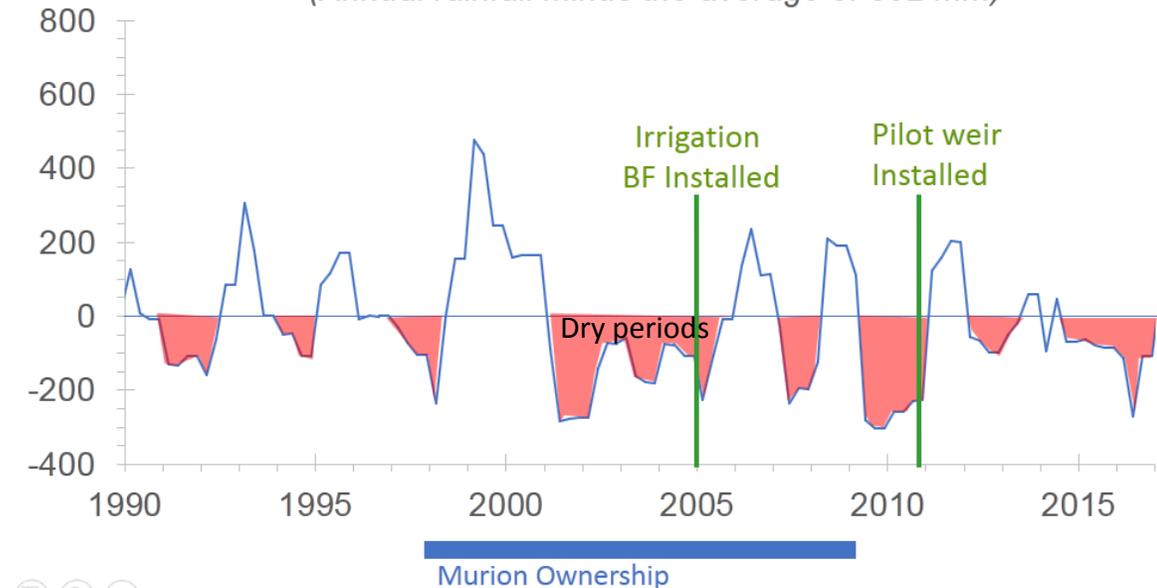
Apart from a brief period between 1998-2009, Minderoo has been Forrester hands since 1878

Stocks **11,000 head** of cattle in good years.

The station was suffered a particularly severe rainfall drought from 2000 to 2006. By 2003 Murion had destocked Minderoo to just **3000 head** and could only sustain the herd at great cost by trucking in fodder from over 1000km away from their Mt Adams Farm in Dongara

Annual Rainfall Deficit over Minderoo

(Annual rainfall minus the average of 302 mm)



Baled sorghum from Mt Adams arrives at Minderoo, 2003

DROUGHT PROOFING MINDEROO

Apart from a brief period between 1998-2009, Minderoo has been Forrest hands since 1878

Stocks **11,000 head** of cattle in good years.

The station was suffered a particularly severe rainfall drought from 2000 to 2006. By 2003 Murion had destocked Minderoo to just **3000 head** and could only sustain the herd at great cost by trucking in fodder from over 1000km away from their Mt Adams Farm in Dongara

In 2005 Murion Cattle Company constructed a borefield and centre pivot irrigator try to make Minderoo more **drought resistant** at **3000 head**



A crop of sorghum grown on the original centre pivot at Minderoo in 2010

DROUGHT PROOFING MINDEROO

Apart from a brief period between 1998-2009, Minderoo has been Forrest hands since 1878

Stocks **11,000 head** of cattle in good years.

The station was suffered a particularly severe rainfall drought from 2000 to 2006. By 2003 Murion had destocked Minderoo to just **3000 head** and could only sustain the herd at great cost by trucking in fodder from over 1000km away from their Mt Adams Farm in Dongara

In 2005 Murion Cattle Company constructed a borefield and centre pivot irrigator try to make Minderoo more **drought resistant** at **3000 head**

The Forrest family took back Minderoo in 2009 with a vision of 11 MAR weirs and 15 pivots to **drought proof** the station at **11,000 head** carrying capacity

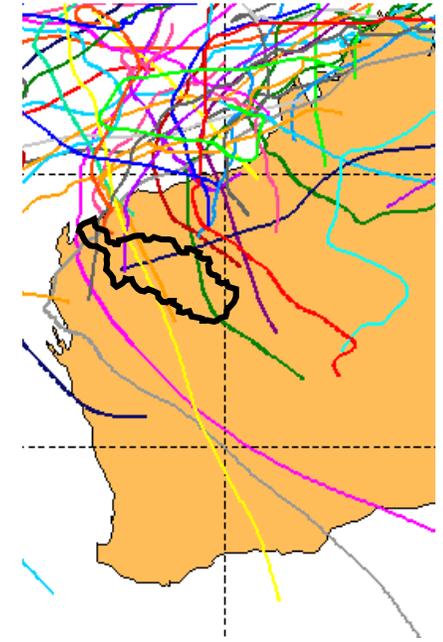


Andrew Forrest on Minderoo Station (ABC News, March 2015)

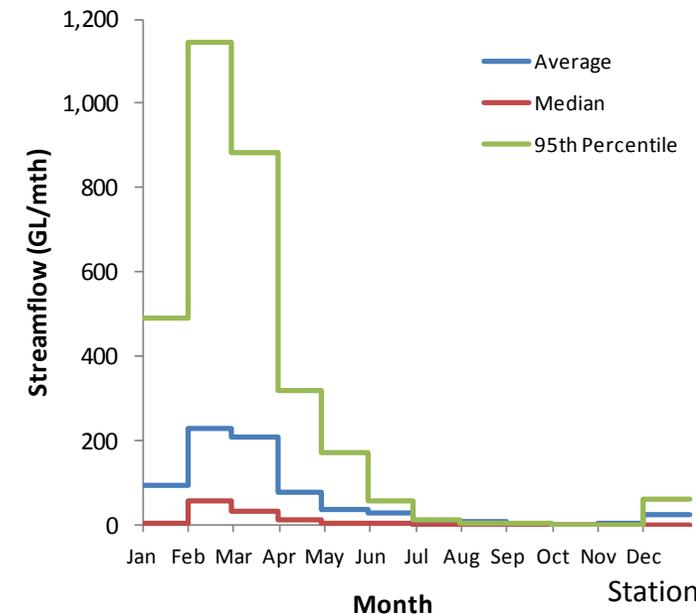
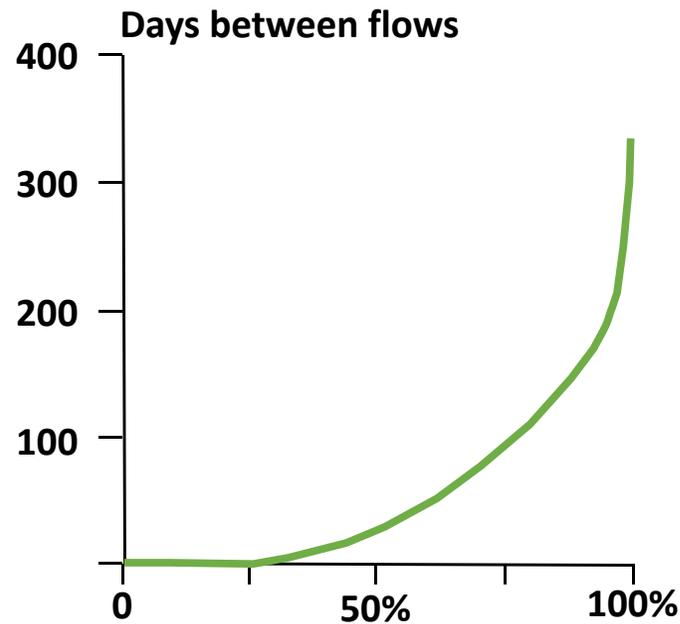
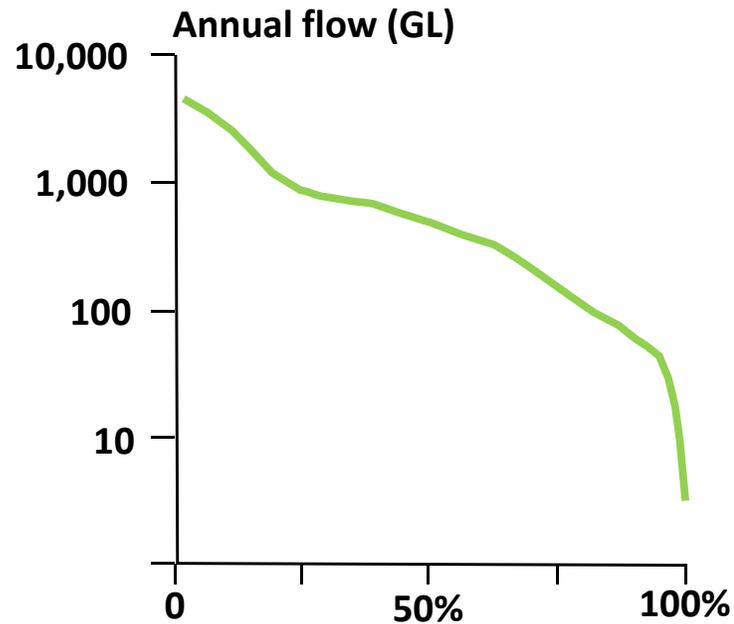
MINDEROO SURFACE WATER RESOURCES

Ashburton River Hydrology

- 95 percentile annual streamflows are between 20 and 2700 GL/a
- The river has flowed every calendar year since 1972,
- Only one period of more than a year that the river didn't flow (20 months)
- Streamflows peak during the cyclone season (Feb, Mar, Apr), but can occur anytime between Dec through to Jul
- 20,000 km² EW catchment captures runoff from most cyclones



Cyclone tracks 1996-06 (BoM)



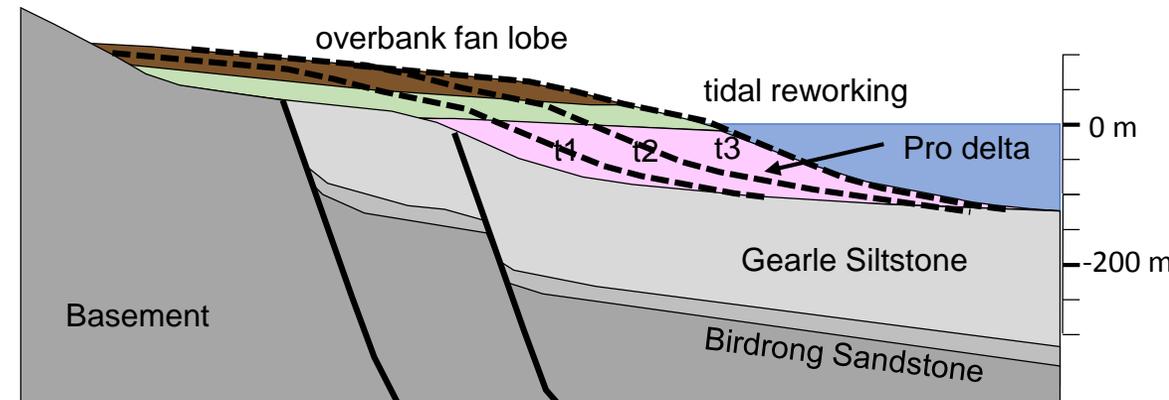
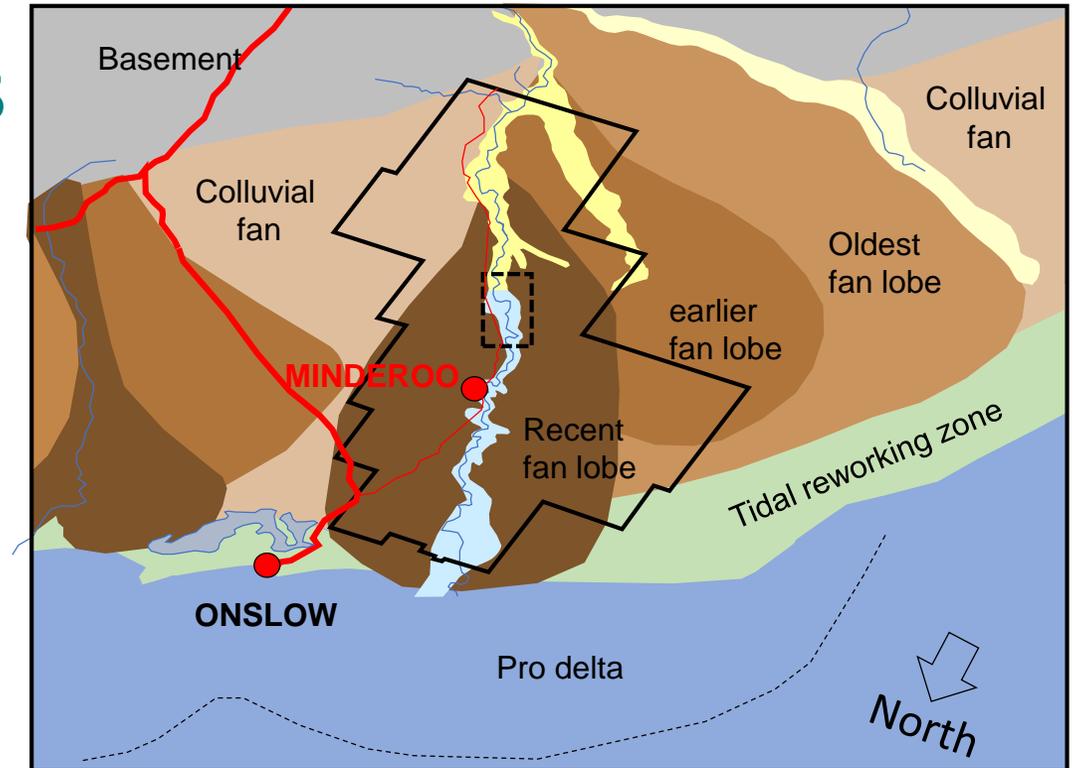
Station: Nanutarra Bridge

MINDEROO GROUNDWATER RESOURCES

Ashburton River fluvial-alluvial delta fan

- Ashburton River transports a huge seasonal sediment load
- this sediment is deposited in a massive 90km radius terrestrial fluvial delta
- The terrestrial fan transitions into a marine pro-delta beyond the coast
- calcrete replacement is common in the tidal reworking zone
- The delta comprises interlaid fan lobes and channel facies of different ages
- The Ashburton now follows a recent course which is likely less than a few tens of thousands of years old

Ashburton fluvial-alluvial delta isometric view looking SSE



Schematic geological section through the Ashburton delta looking W

MINDEROO GROUNDWATER RESOURCES

Borefield development considerations

Aquifer permeability and storage properties are best developed in the sandy and gravelly alluvial channel facies

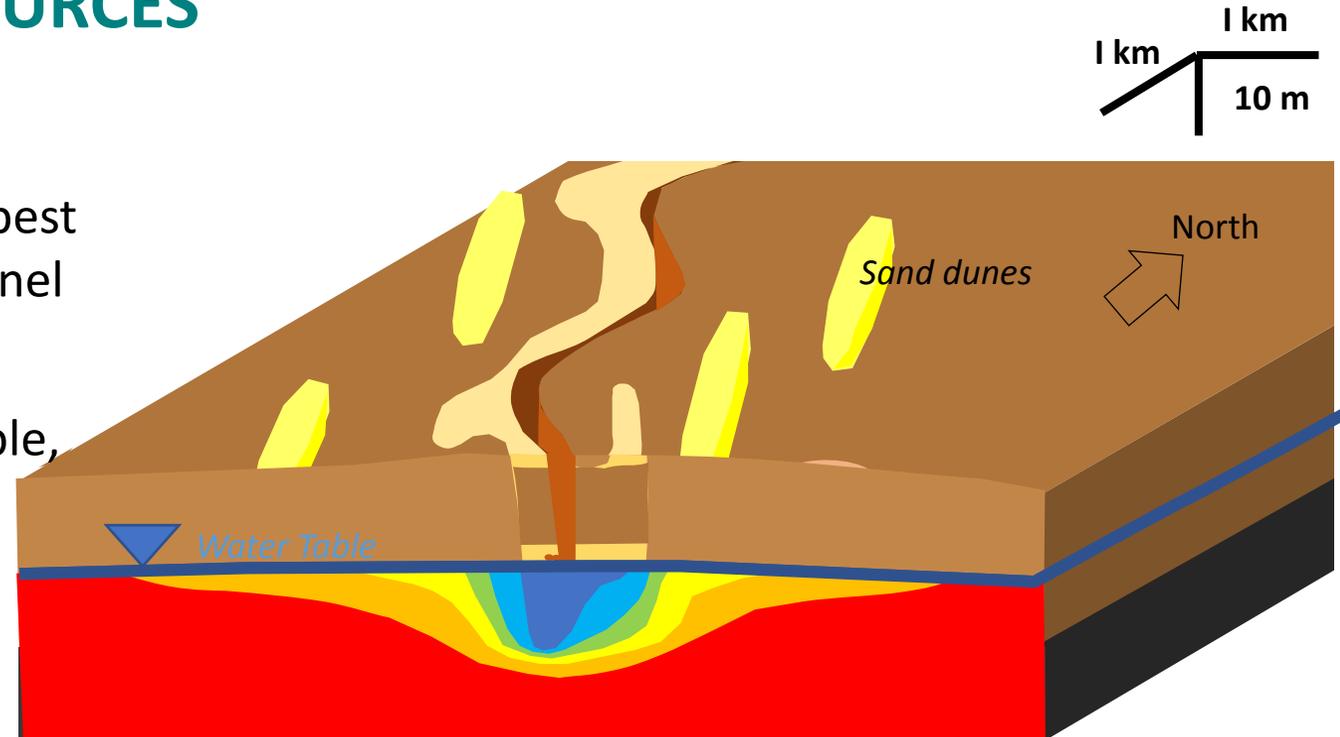
Over-bank deposits tend to be silty, less permeable, and have poorer quality groundwater

Groundwater is hypersaline near the coast

The palaeochannel aquifer meanders from one side of the river to the other

The stratigraphy of the channel deposits is highly variable making it difficult to predict bore yields

Over pumping risks saline encroachment from the silt deposits



Groundwater Quality

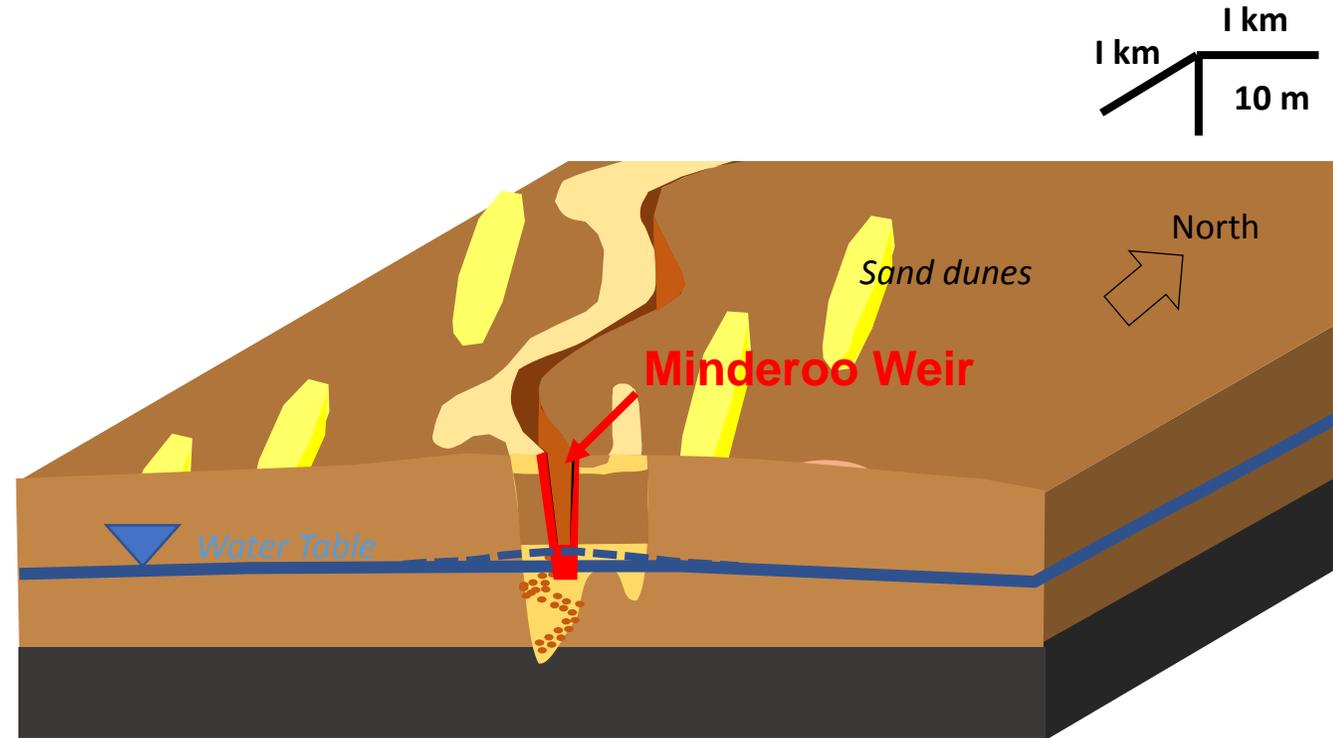
Less than 600
600 to 1,000
1,000 to 3,000
3,000 to 6,000
6,000 to 14,000
14,000 to 30,000
More than 30,000

MINDEROO MAR SOLUTION

Use of upside-down weirs to enhance recharge of the borefield resources

Weir design constraints

- The channel bank comprises mostly highly erodible overbank silt deposits
- River channel is 12 metres deep and 100m wide
- Water table is also deep, being 12m below ground
- The channel deposits are 30m deep and can be between 1 and 3km wide
- Any obstruction in the river might risk flooding and/or a change in the river course



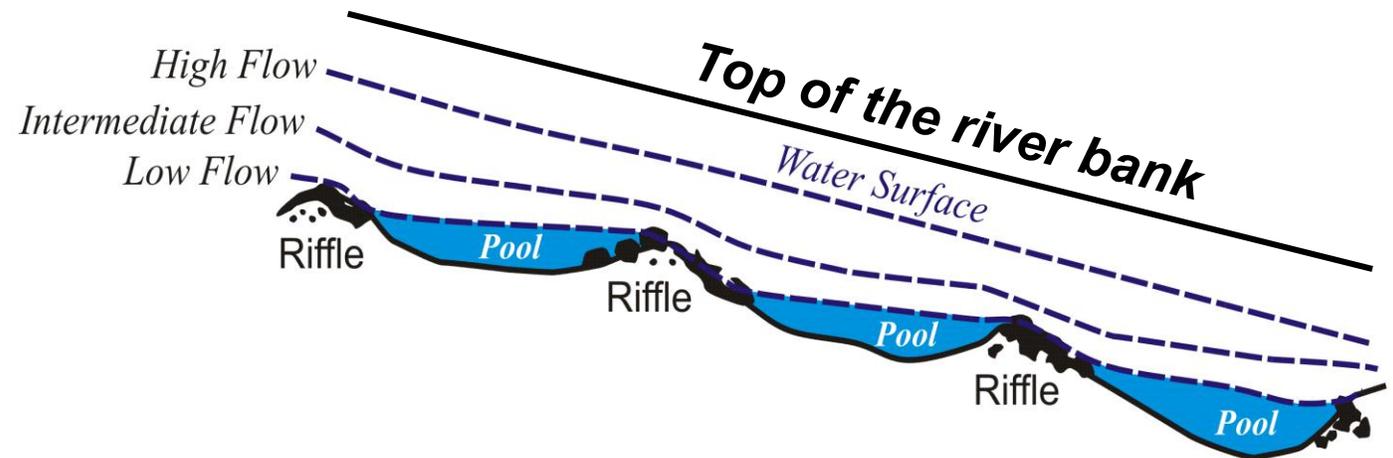
The solution for Minderoo was a series of engineered partially penetrating leaky low weirs in the river channel

MINDEROO MAR SOLUTION

Use of upside-down weirs to enhance recharge of the borefield resources

Weir design constraints

- The channel bank comprises mostly highly erodible overbank silt deposits
- River channel is 12 metres deep and 100m wide
- Water table is also deep, being 12m below ground
- The channel deposits are 30m deep and can be between 1 and 3km wide
- Any obstruction in the river might risk flooding and/or a change in the river course

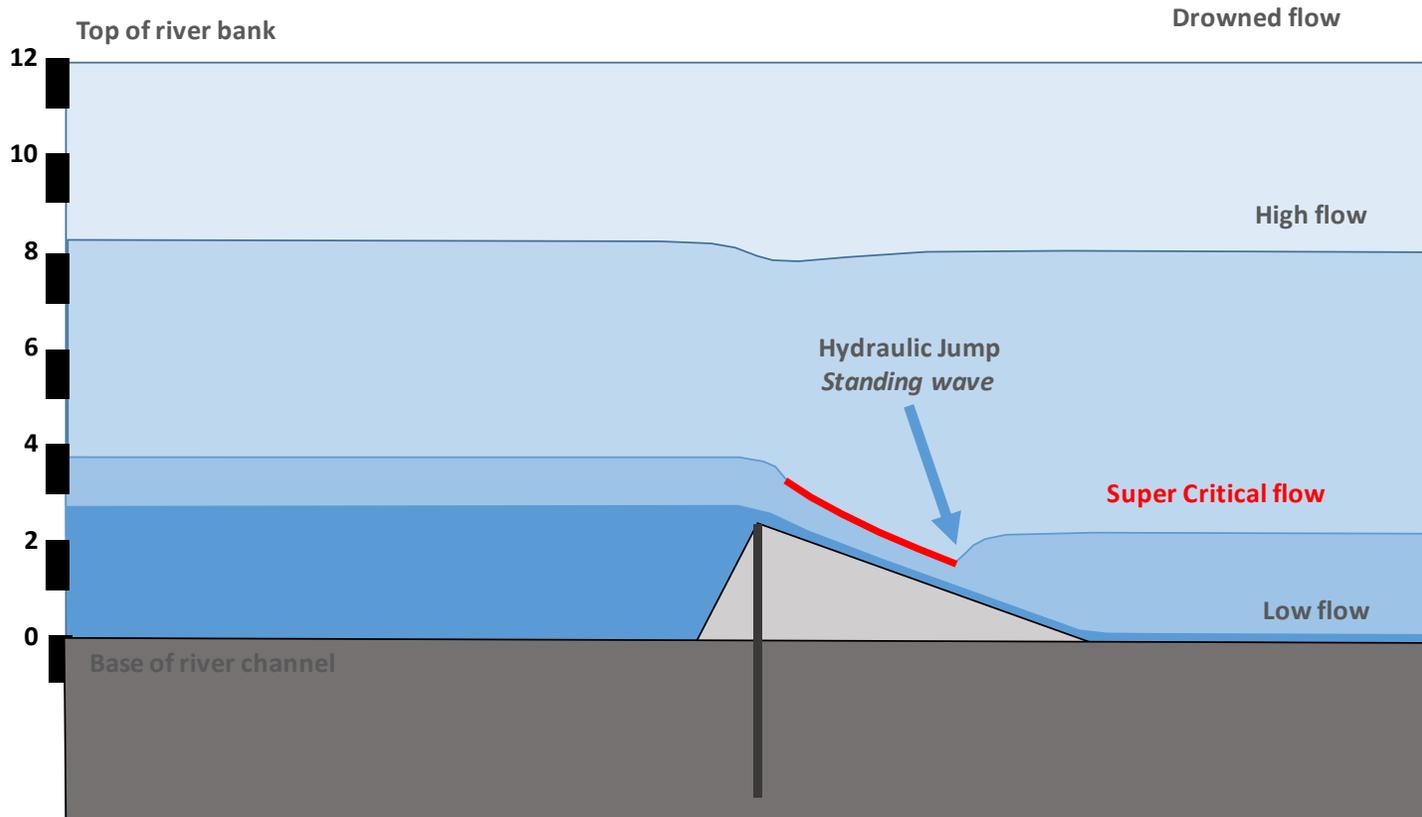
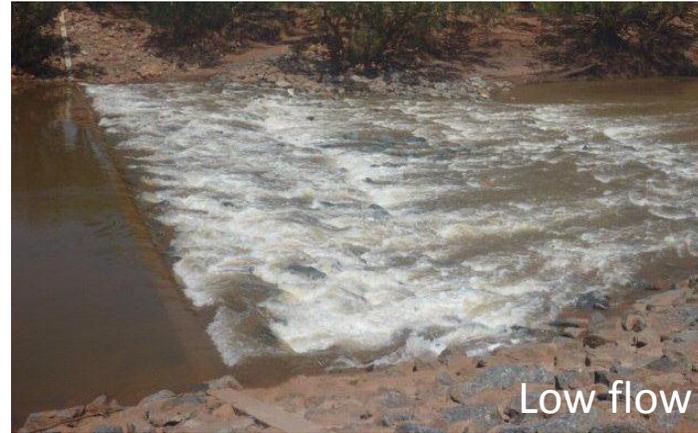


Water and Rivers Commission 2001, Stream Channel Analysis Report No RR9

The solution for Minderoo was a series of engineered partially penetrating leaky low weirs in the river channel, with leakage from upstream weirs sustaining the groundwater mound in the lower weirs

MINDEROO MAR SOLUTION

Weir scour and bank erosion considerations

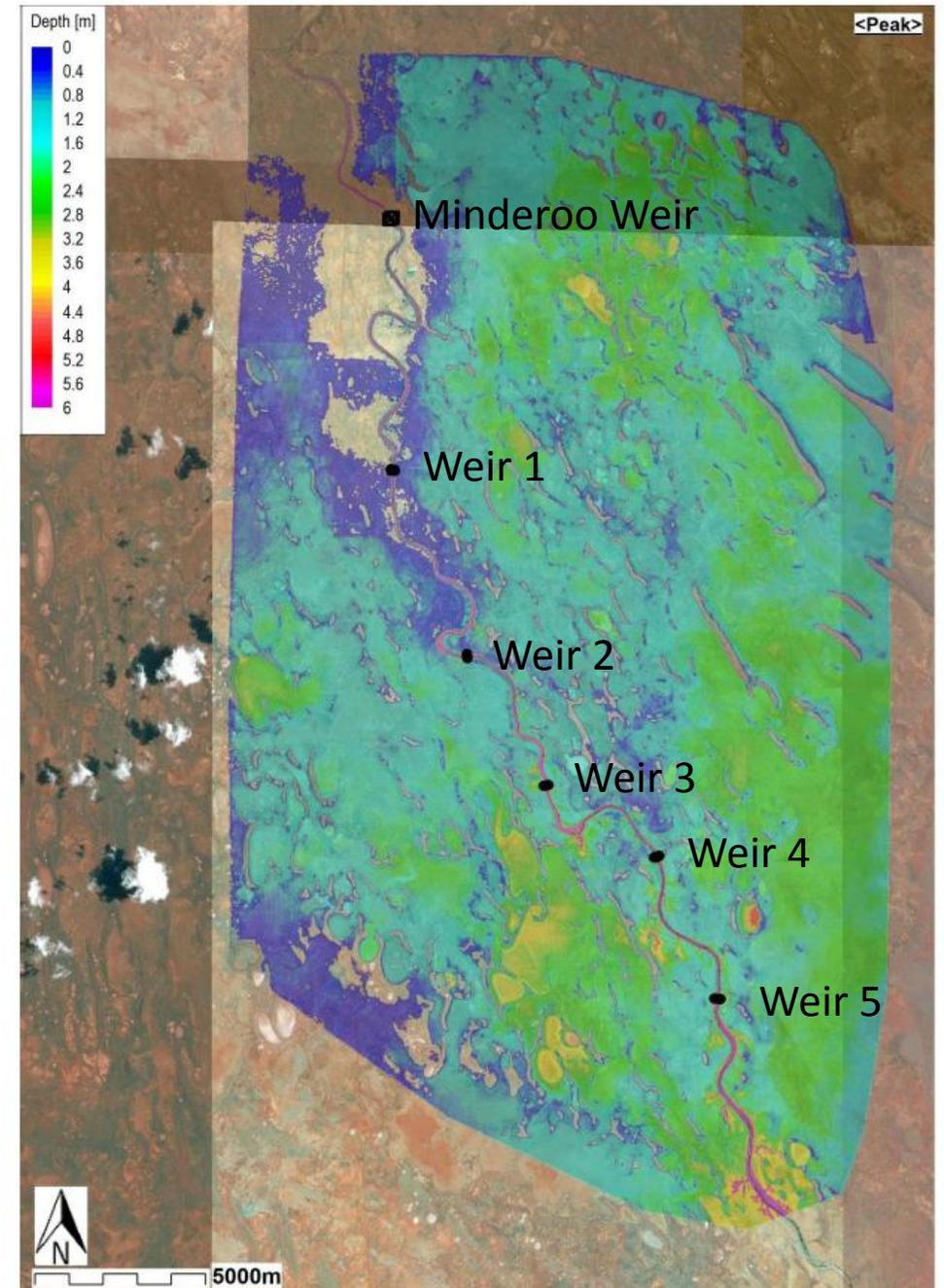


MINDEROO MAR SOLUTION

Flood risk considerations

Study Findings

- Flood water would naturally overbank the Ashburton River channel in each of the 20, 50 and 100 yr ARI streamflow events
- The weirs have minimal effect on flood levels or velocities in the floodplain area; and
- The incremental flood risk attributable to the weirs would not be discernible above the flooding that would otherwise naturally occur during these events



TUFLOW 2D hydraulic modelling of 100 yr AIR flood due to weirs (Advisian 2016)

MINDEROO MAR SOLUTION

Sediment transport considerations

Study Findings

- Each weir creates a low backwater pool which can extend up to 6 km upstream of the weir and impounds about 300 ML.
- While a small proportion of the river sediment load is deposited in the weir pool between flushing events; flows that are large enough to scour out and remobilise this silt over the weir crest occur, on average, several times a year.
- The weirs do not impact the overall rate of siltation or sediment transport either behind the weir pool or downstream of the weir.



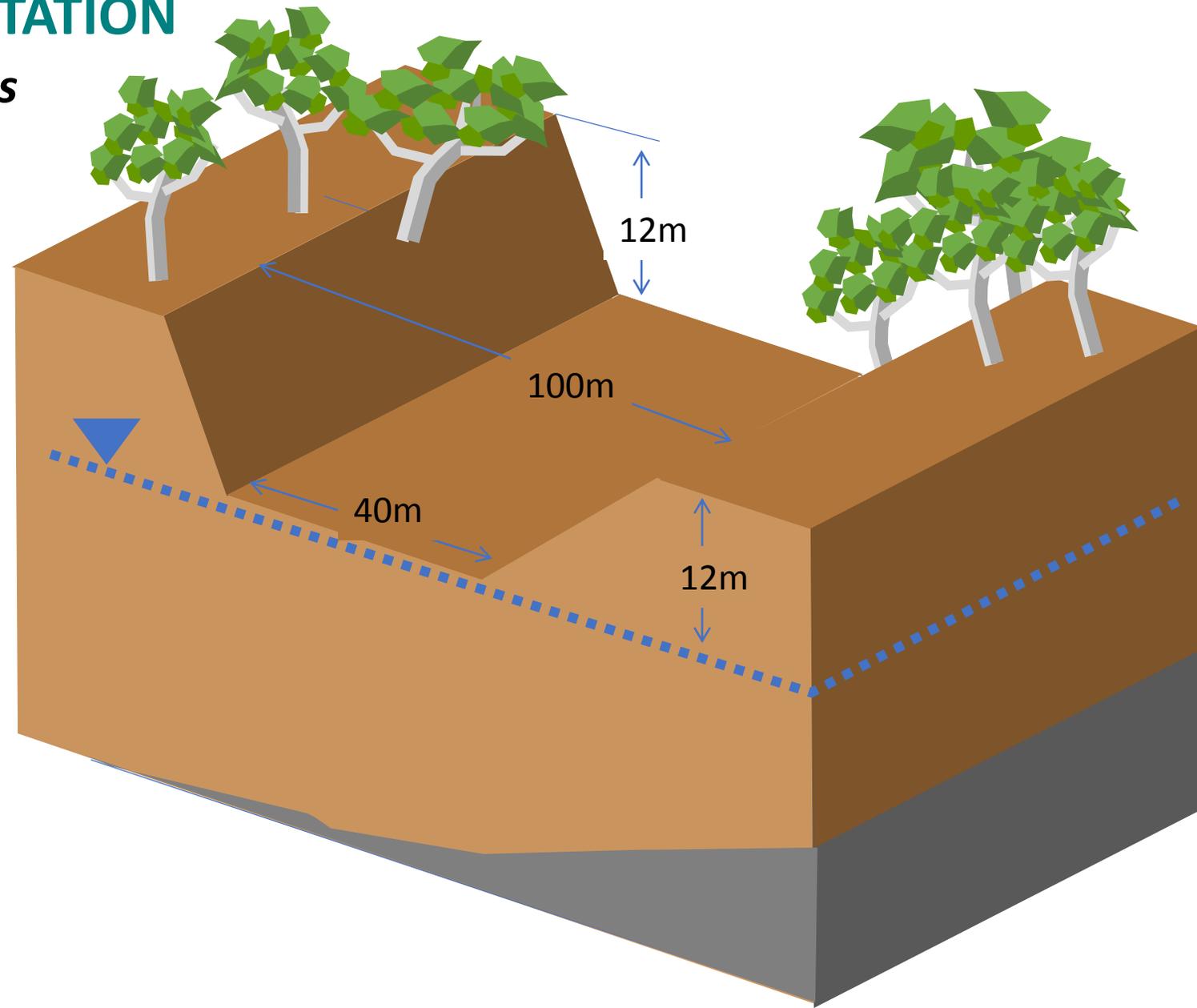
MINDEROO MAR IMPLEMENTATION

Construction of upside-down weirs

Original channel



Bank before weir construction in 2005



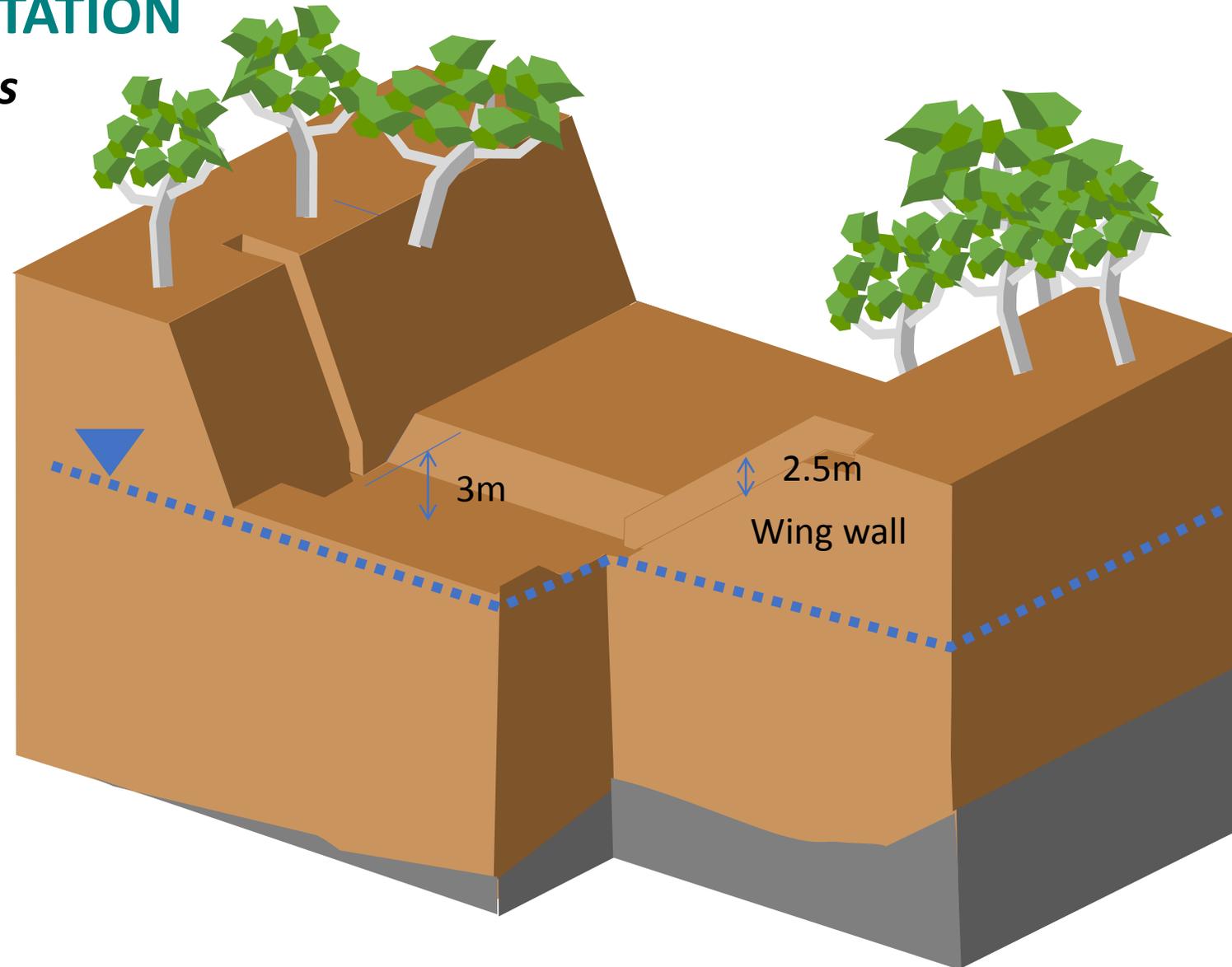
MINDEROO MAR IMPLEMENTATION

Construction of upside-down weirs



Construction in 2010

Excavation Phase



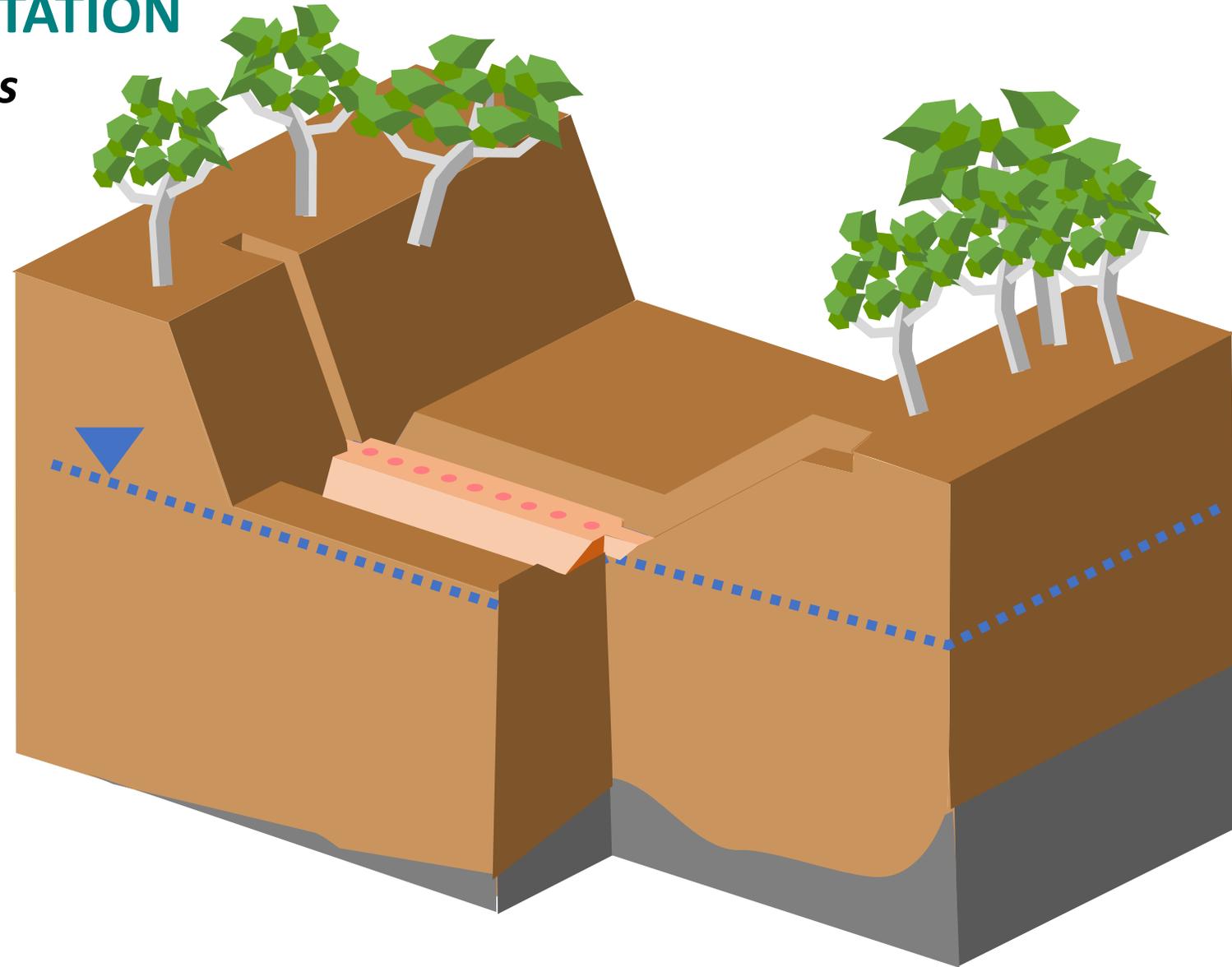
MINDEROO MAR IMPLEMENTATION

Construction of upside-down weirs



Stabilised fill and augur holes for rebar

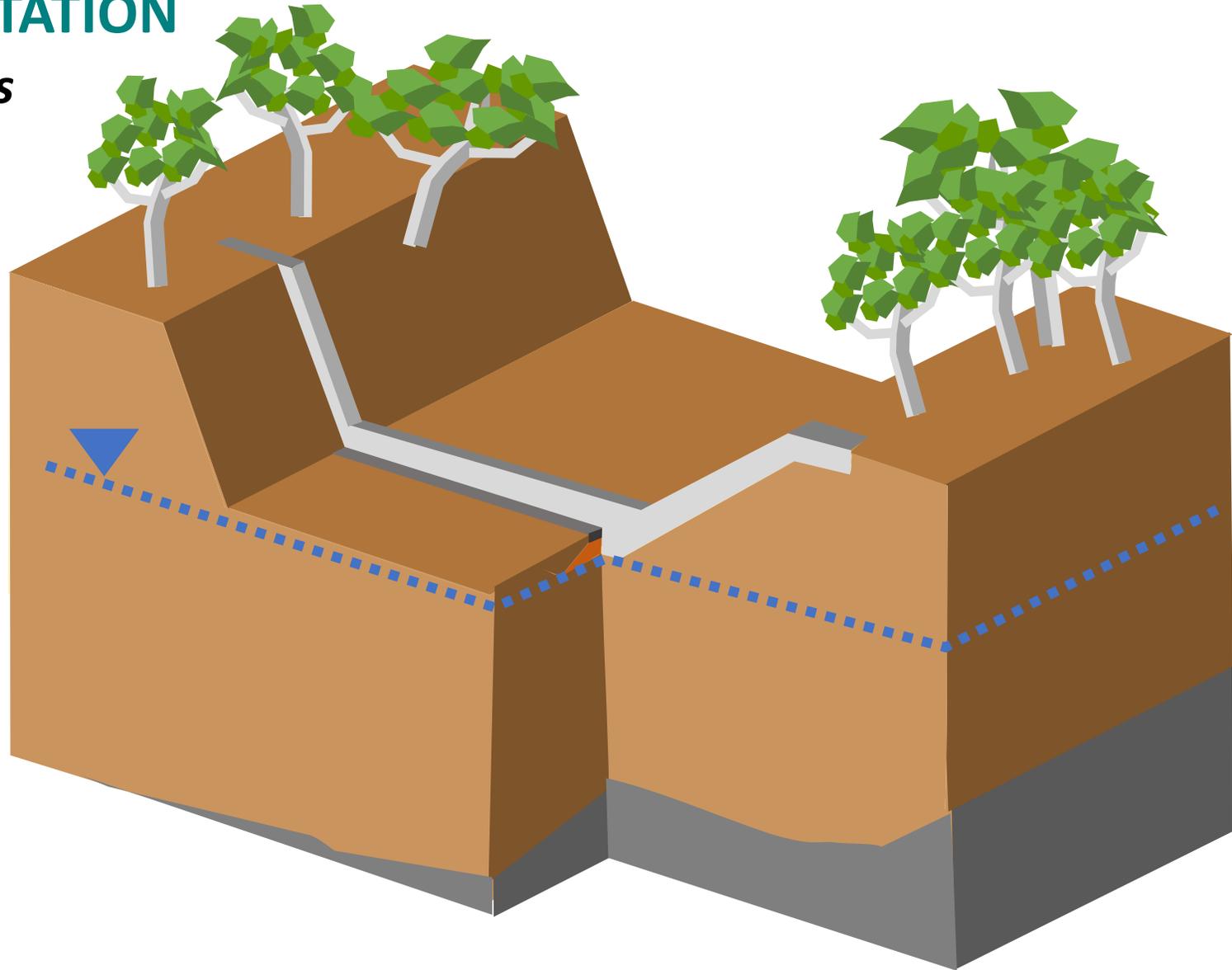
Grout stabilised fill



MINDEROO MAR IMPLEMENTATION

Construction of upside-down weirs

Concrete Weir Core



Reinforced concrete weir wall core

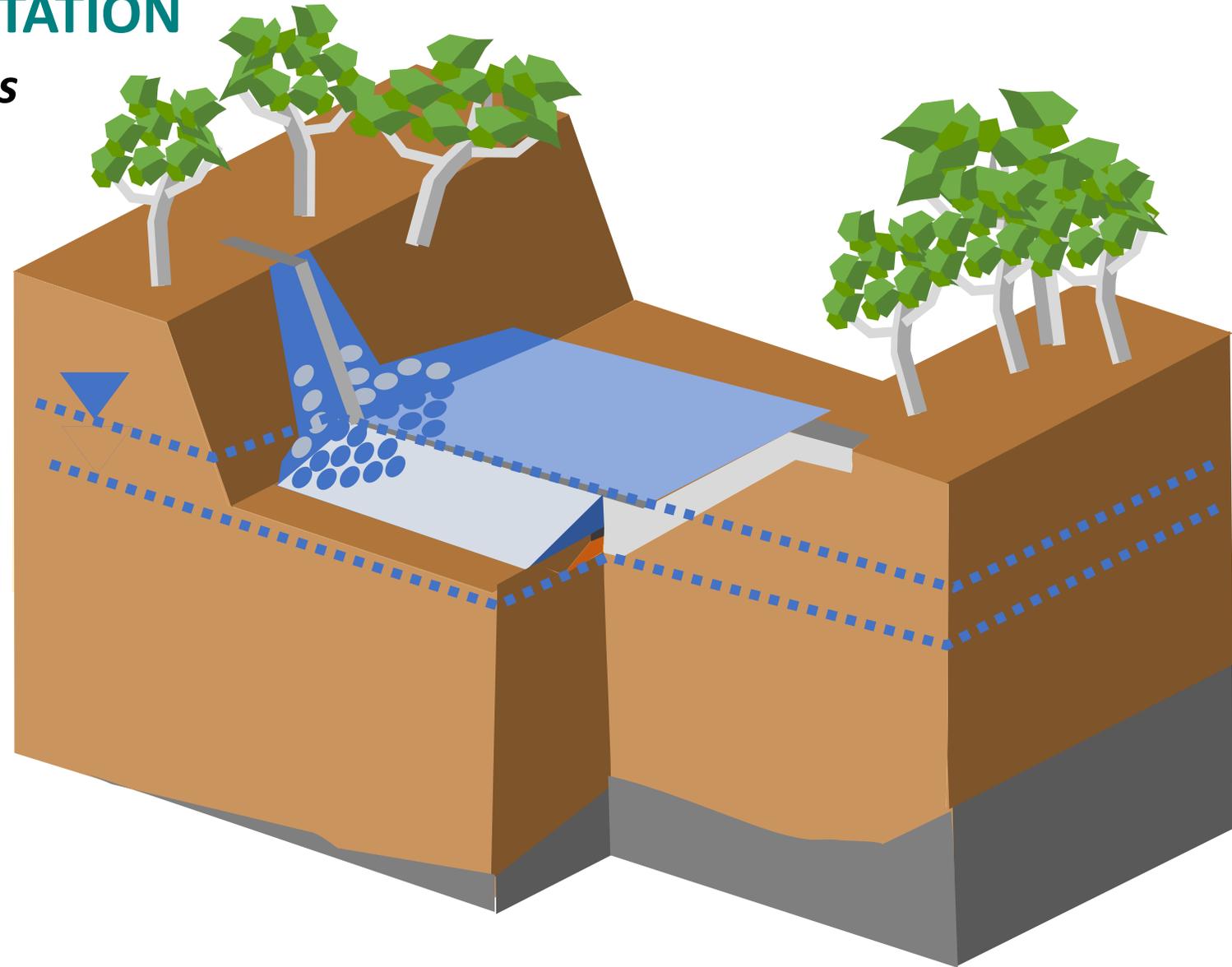
Weir shaping and rip rap

MINDEROO MAR IMPLEMENTATION

Construction of upside-down weirs

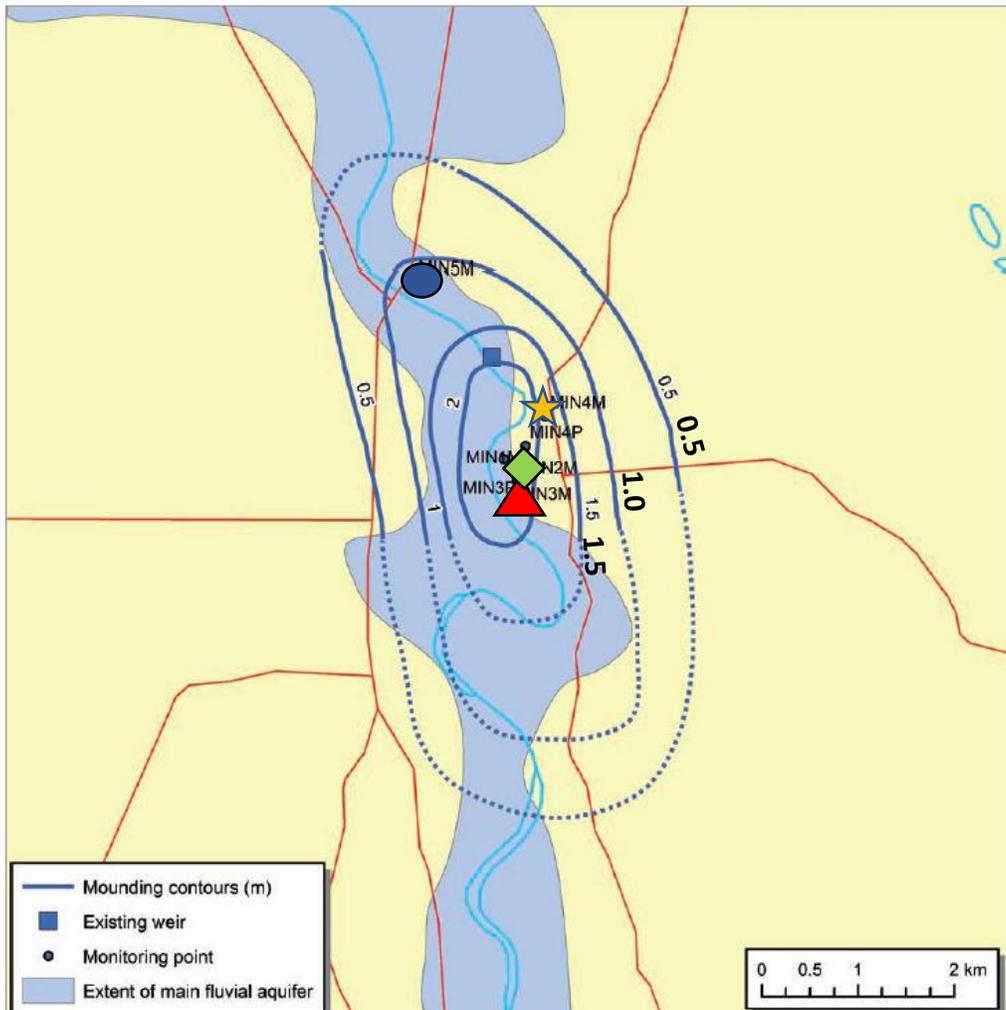


Placement of mafic rip rap

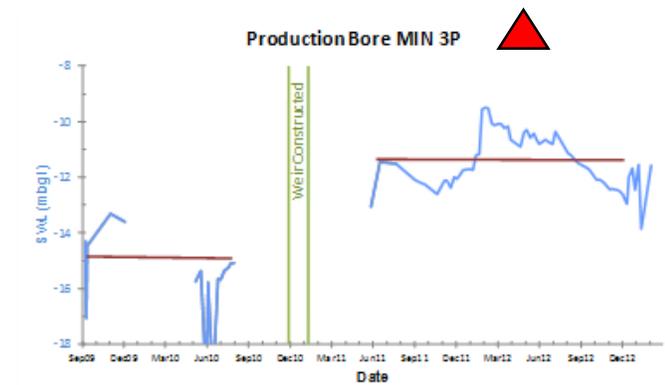
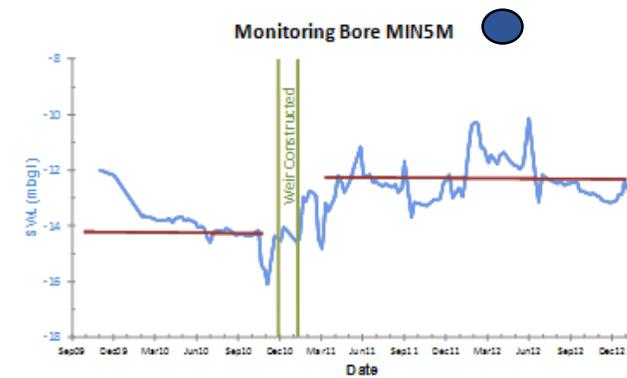
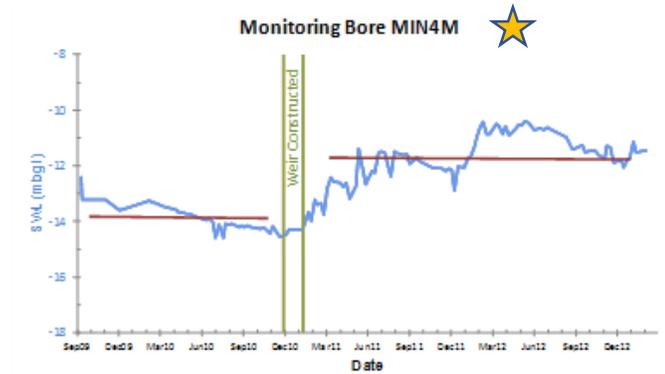
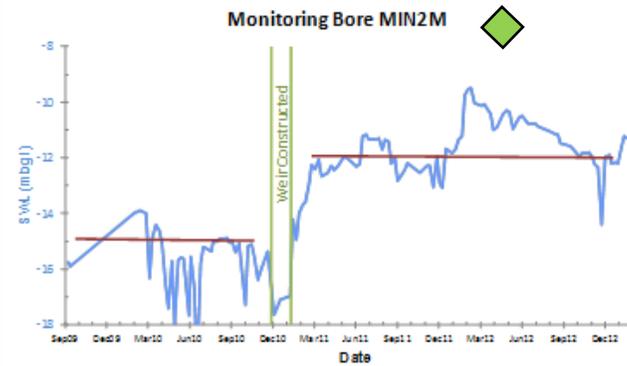


MINDEROO MAR PERFORMANCE

Groundwater mounding after weir



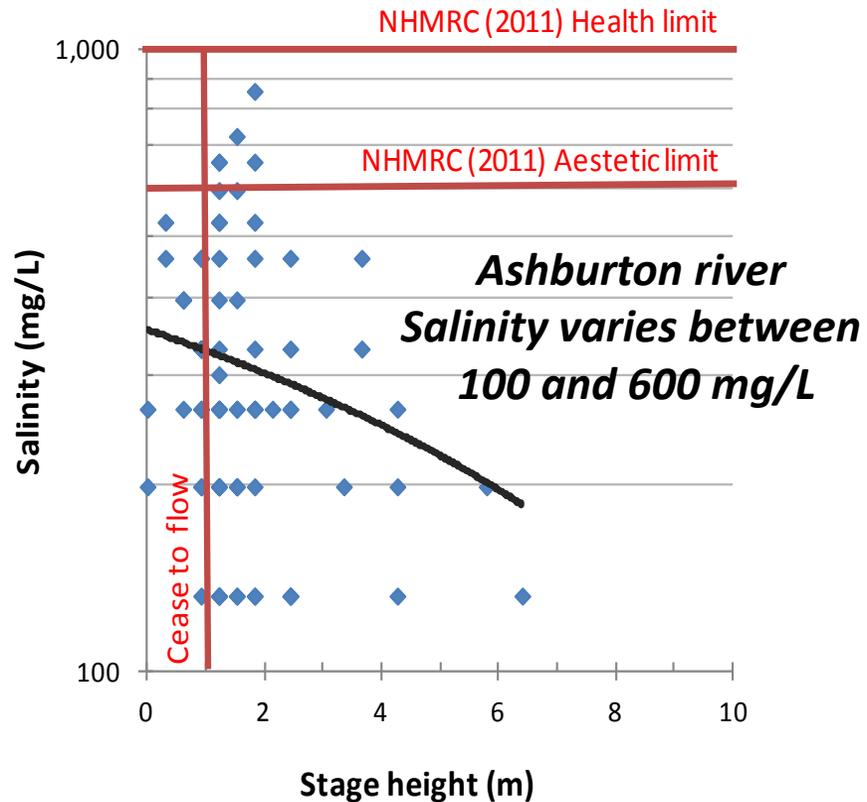
OBSERVED CHANGE IN BORE WATER LEVEL AFTER THE WEIR



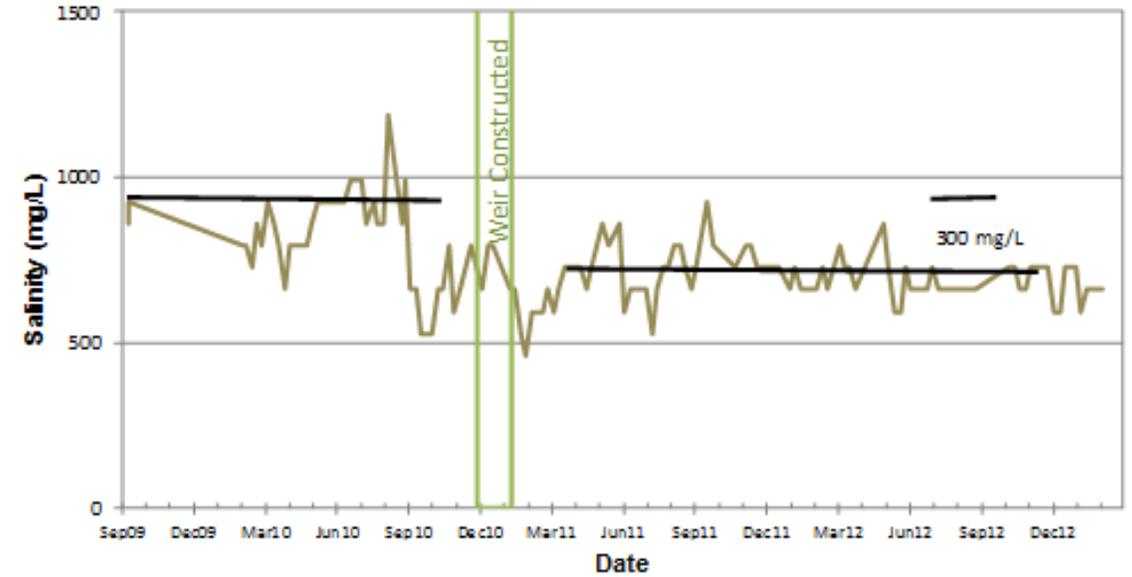
MINDEROO MAR PERFORMANCE

Groundwater salinity conditioning

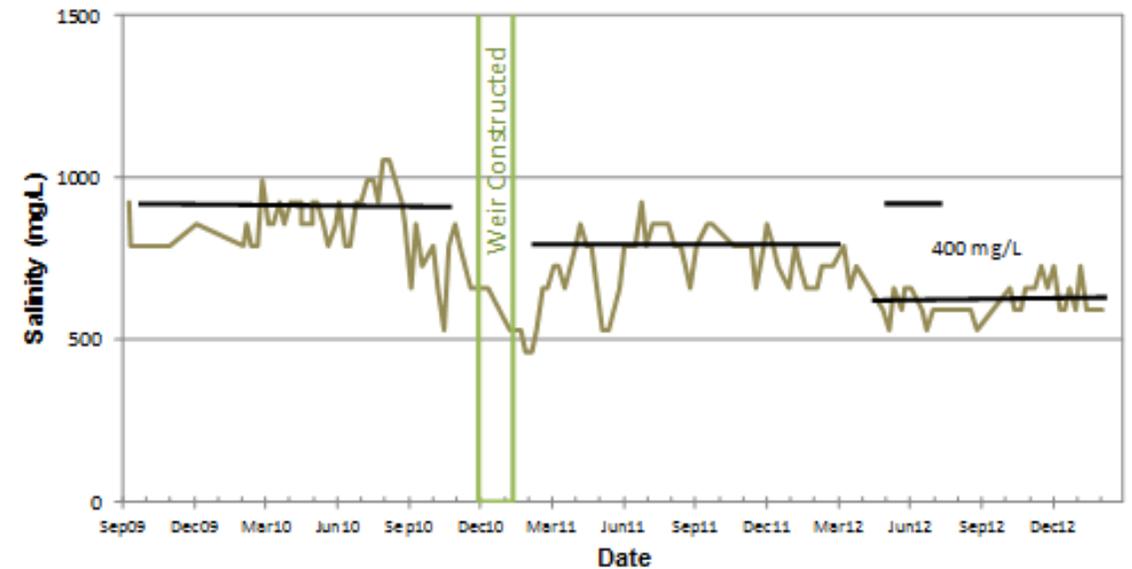
RIVER FLOW SALINITY AT MINDEROO BRIDGE



Monitoring Bore MIN2M



Monitoring Bore MIN4M

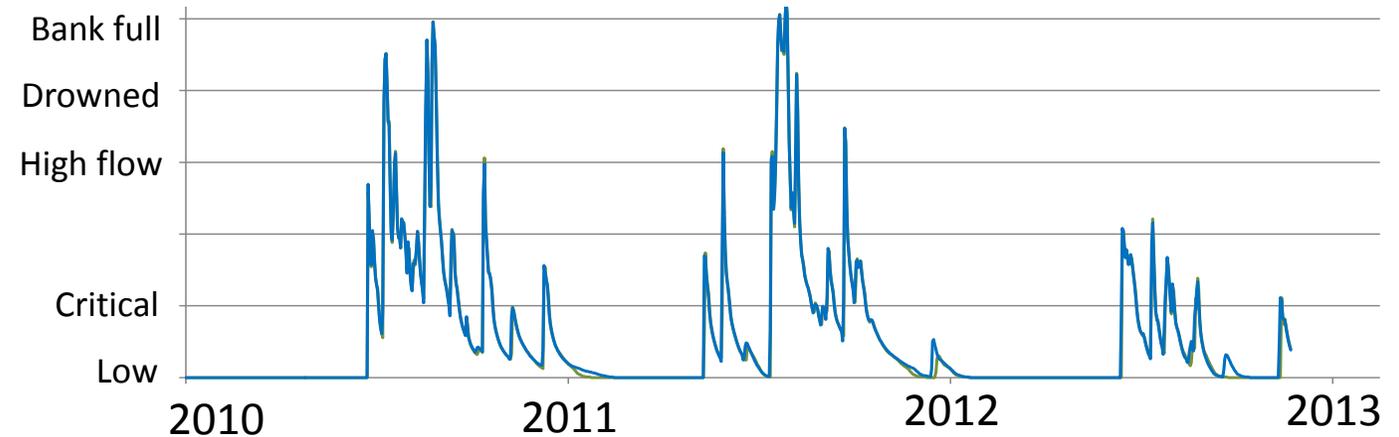


MINDEROO MAR SOLUTION

Fish migration impacts after the weir

- Some salt water fish species can negotiate the weir at low flows; no species migrate at critical flow; all species can negotiate the weirs in drowned flows, which occur on average seven days of the year, generally in one or two events
- The weirs may provide security of water to parts of the Ashburton River which would otherwise be historically dry, creating a greater extent of habitat available to fish for a longer duration than previously encountered.
- Barramundi, Mangrove Jack and Sea Mullet (saltwater species) have been recorded in Minderoo pool in 2012

STAGE RIVER HEIGHT ABOVE MINDEROO WEIR



CONCLUSIONS

- The sustainable cattle carrying capacity of Minderoo Station has historically been limited by rainfall drought cycles
- Minderoo uses groundwater from the Ashburton Alluvial aquifer to grow fodder to drought proof the station at higher cattle carrying capacity
- The deployment of upside-down weirs in the river channel (low leaky partially penetrating cut-off walls) not only freshens the aquifer salinity; it also impounds up to 300 ML in a pool behind the weir plus also banks a further gigalitre in a groundwater mound around each weir after each flow event
- Both the groundwater mound and the wear pool leak away and dissipate back into the river downstream over a few months, thus attenuating rather than damming flows
- Multiple weirs have the advantage that leakage from the upper weirs flow into the pools of the lower weirs, thus further attenuating the recharge of the borefield



Andrew Forrest at the Minderoo Weir (ABC News, July 2017)

WGA

WALLBRIDGE GILBERT
AZTEC

Implementation and Testing Setting up a MAR Site

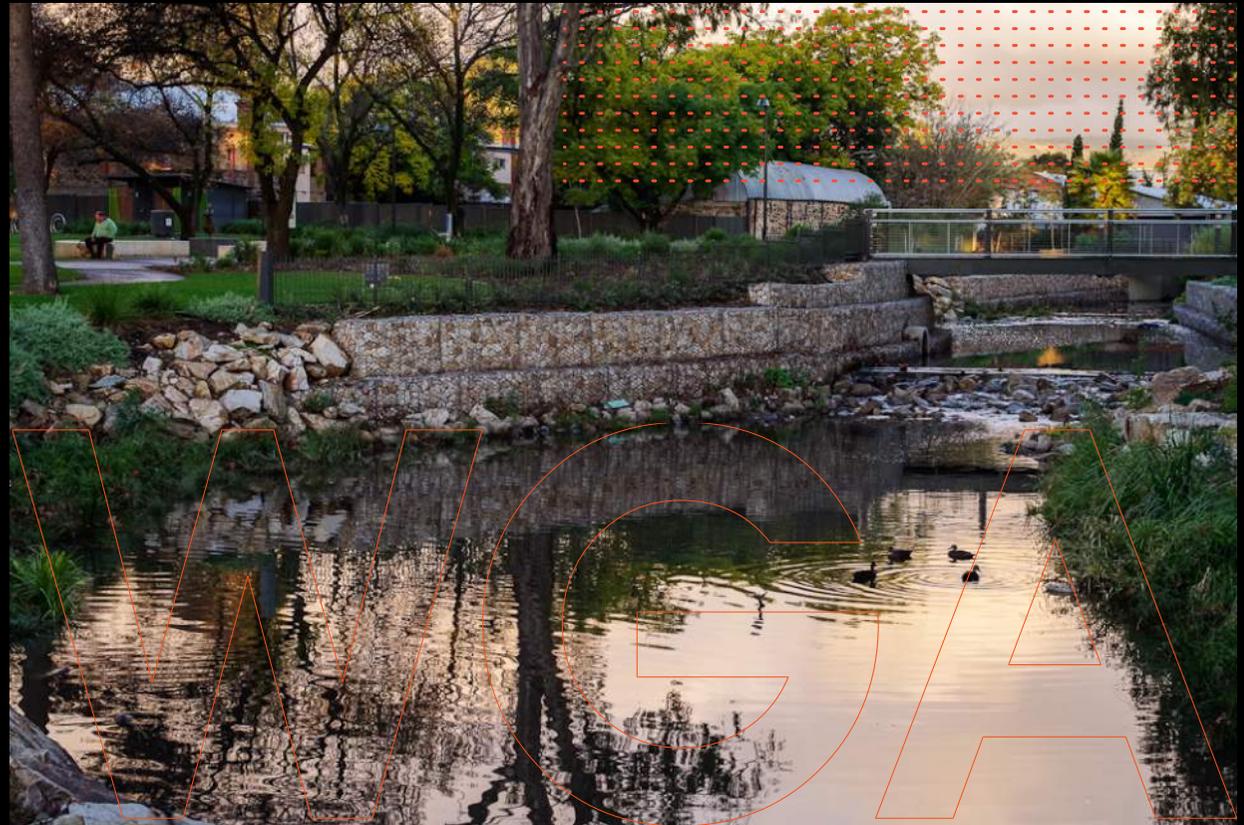
October 2017

RUSSELL MARTIN
Principal Hydrogeologist

rmartin@wga.com.au
ph +61 438 110 700

www.wga.com.au

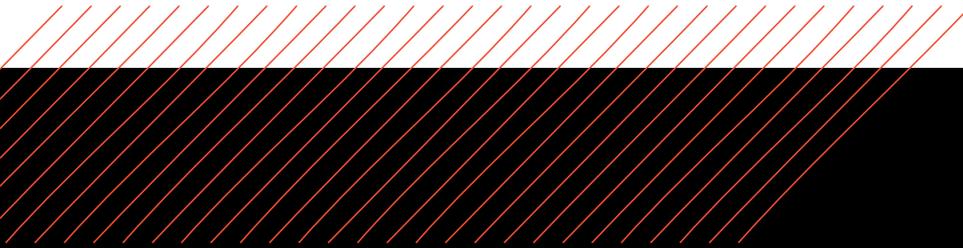
45 minutes



Outline

1. Aquifer characterisation
2. MAR Investigations
3. Aquifer hydraulic testing
4. Geochemistry
5. Design & Construction
6. Monitoring & Management



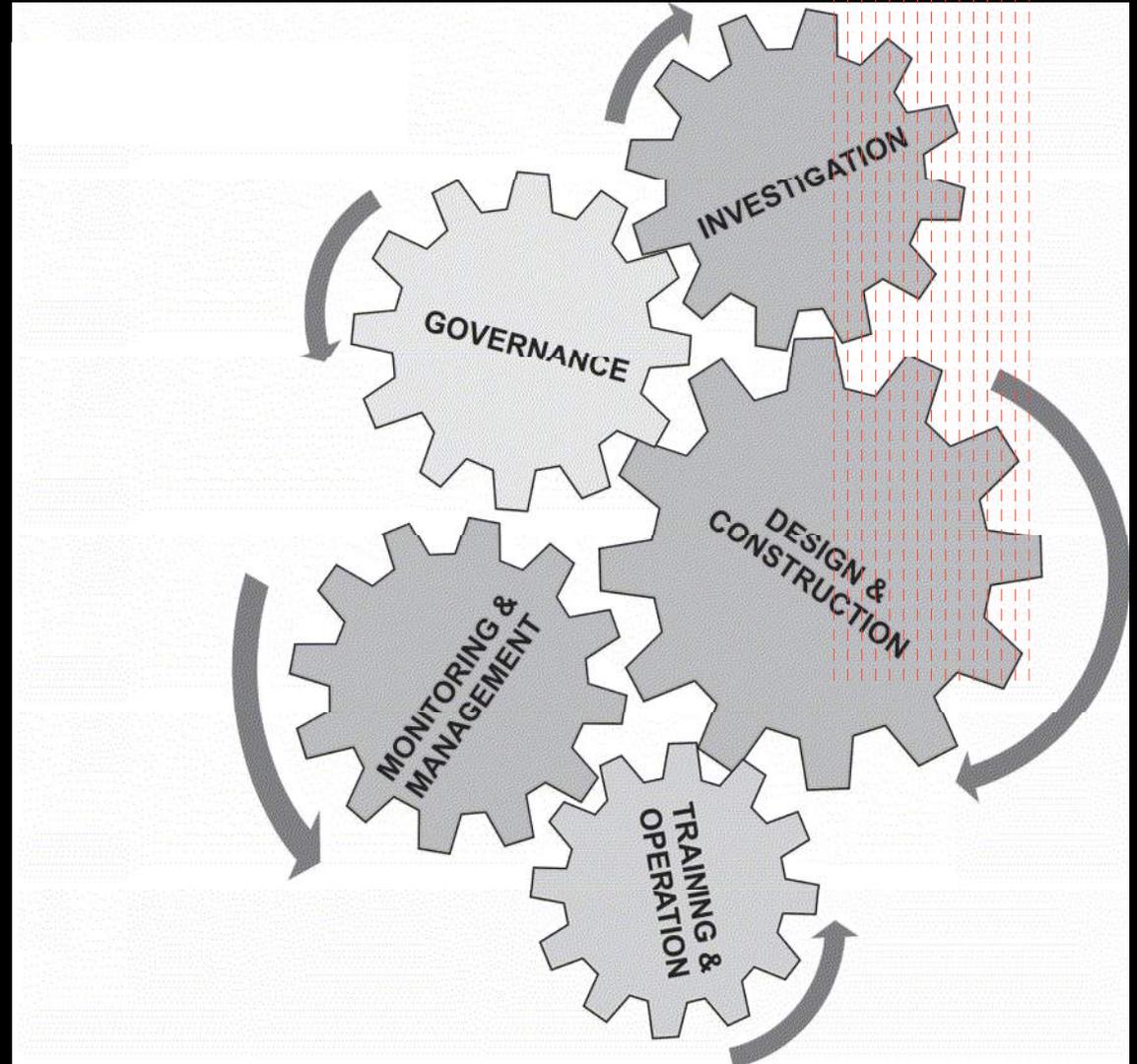


Aquifer Characterisation

- The key to a successful and sustainable MAR scheme is the detailed characterisation of the aquifer.
- It will inform:
 - Well design & completion
 - Trial requirements and duration
 - Groundwater Numerical Modelling
 - Hydrogeochemical modelling
 - Risk assessment
 - Scheme design and level of additional mechanical treatment that may be required to mitigate against clogging and Well failure
 - Identification of operational measures that will prevent clogging
- Well design and completion especially development following the final construction. This is a critical aspect to mitigate against well failure.

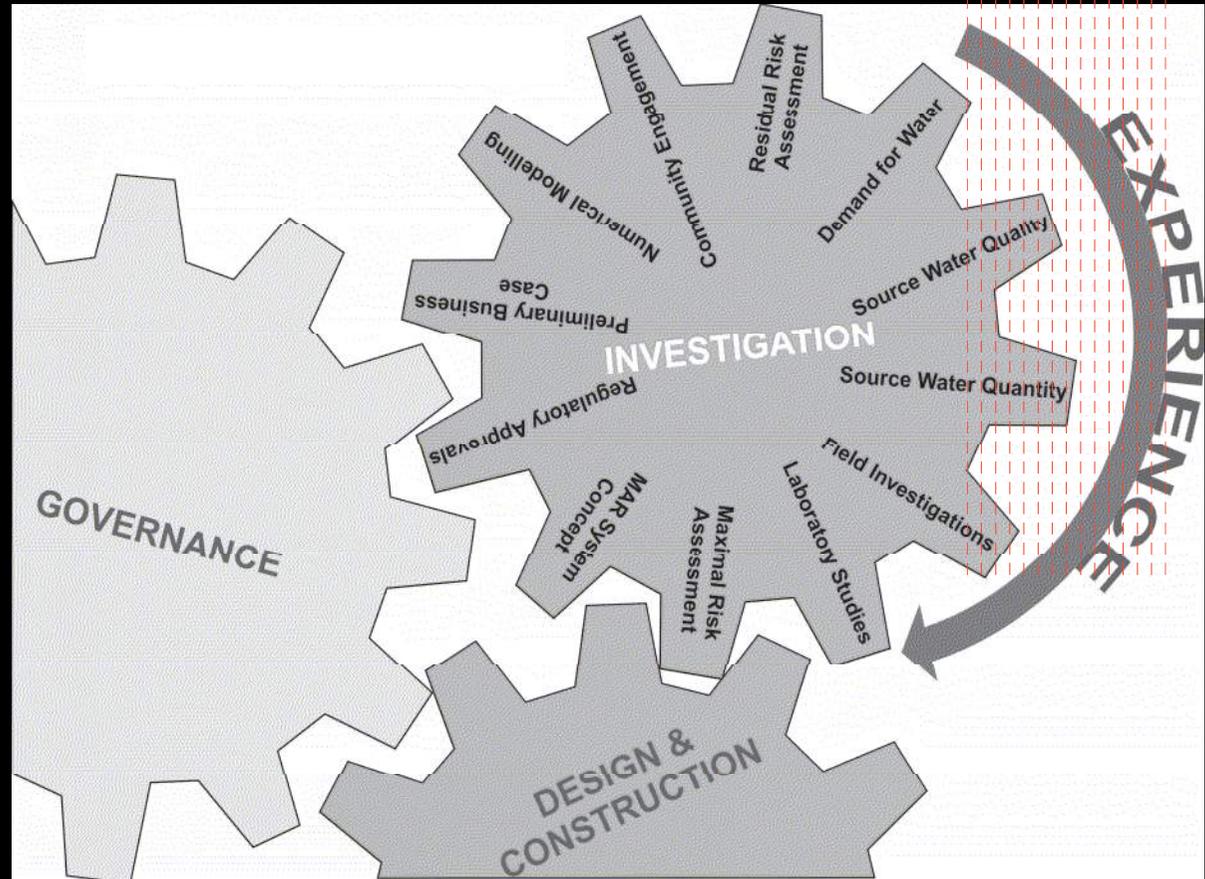
MAR System

- MAR systems are not simple!
- Require an integrated team to deliver (Hydrogeologists, Economists, Engineers, Microbiologists, Planners etc.
- Following each stage auditing of results and outcomes should be completed by independent experienced practitioners.



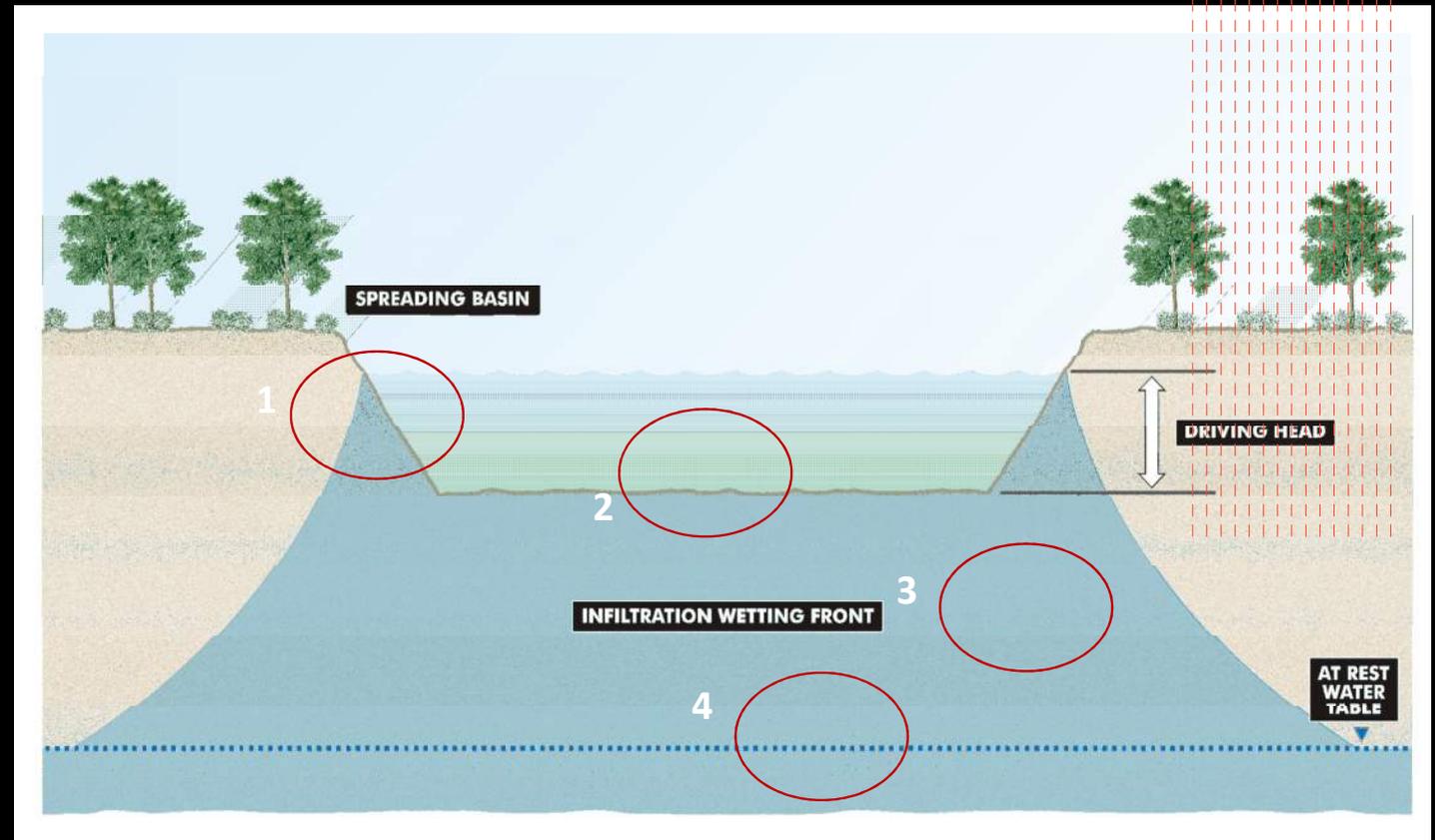
MAR Investigations

- Need to define and prioritize objectives, as a first step in any MAR program.
- Why MAR?
- When is the source water available?
- What is the quality of the source water?
- Where is the demand for the water?
- How is the scheme to be operated to manage risk?



Infiltration Basins

1. Issues with slope and erosion
2. Issues with clogging on basin floor and remediation
3. Issues with wetting front – connectivity between groundwater and basin & air entrainment
4. Issues with reactions between ambient groundwater & injected water



Infiltration basin floor



Smearing of these fine clay "biscuits"
causes "skin effect"



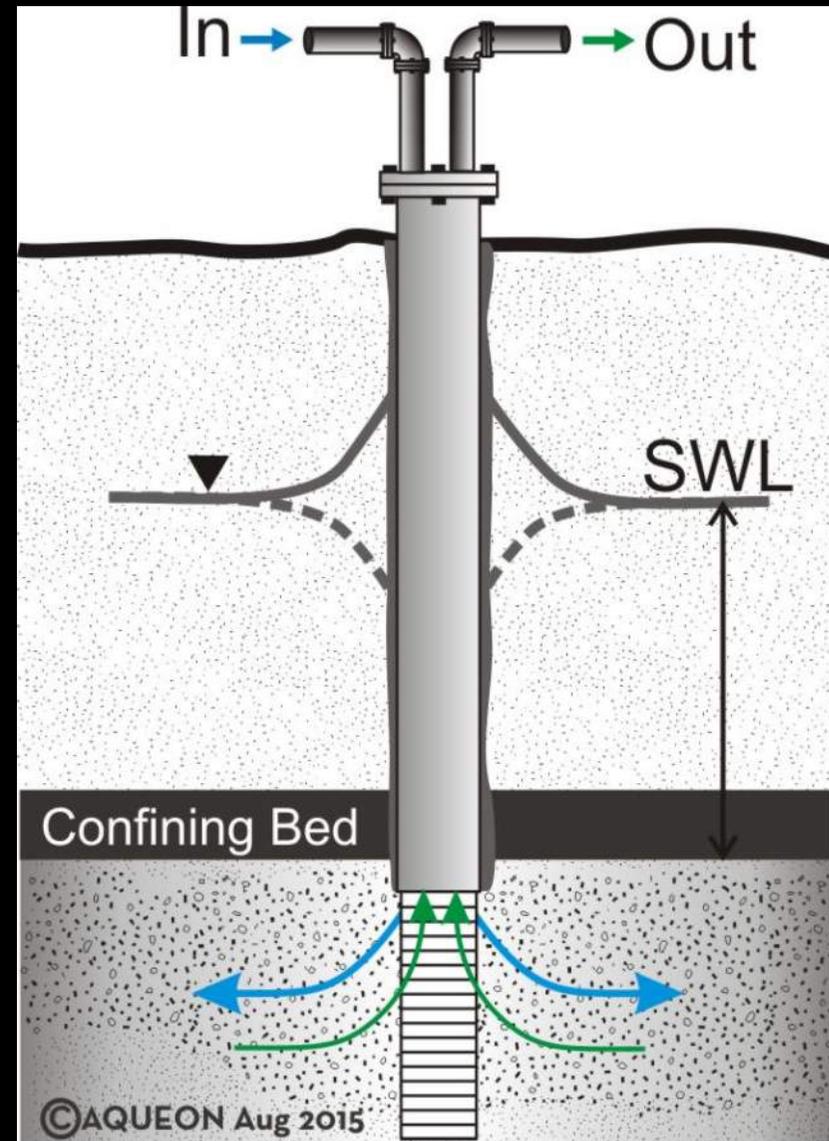
Infiltration galleries

- Key consideration is ability to undertake maintenance



ASR Bores

1. Drilling method
2. Drilling fluid management
3. Construction
4. Completion
5. Coring
6. Aquifer matrix analysis
 - Laboratory Tests
 - Sieve Analysis
 - Colum studies
 - Mineralogy
 - Cation exchange Capacity
 - Water Quality
7. Bore development
8. Aquifer pumping tests
9. Injection trials



Production zone selection

- Prefer single zones with adequate confinement over multiple zones with higher total yield.
- Case off zones with geochemical or geological constituents that may cause problems e.g. lignite.
- Acidisation can be used to increase well yields and injection rates.
- Where there are two or more storage intervals, need to rely upon a larger buffer zone volume in aquifers where ambient groundwater quality is poor.



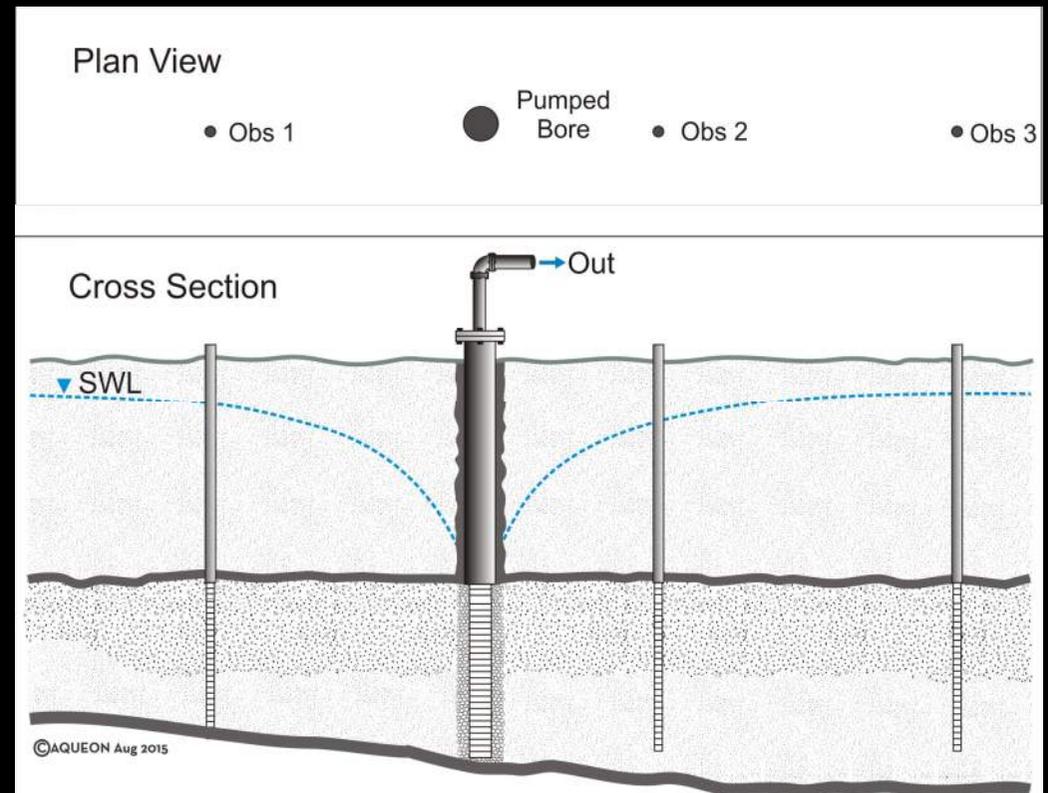


Aquifer hydraulic testing

- Conducted to determine:
 - The capability of the aquifer to sustainably deliver water to the aquifer via percolation of injection well over extended periods of operation.
 - The area influenced by pumping.
 - Lateral boundary conditions that may influence the drawdown.
 - Vertical boundary conditions – upward or downward leakage from underlying or overlying aquifers.
 - Maximum expected drawdown (and injection head) at nominated pumping rates.
 - Pump size and pump depth setting.
 - If a bore's performance is changing over time.
 - A baseline for aquifer capability against which cycles of infiltration or injection and recovery can be measured to assess scheme operation.
 - For infiltration basins critical to understand the relationship between K_v and K_h

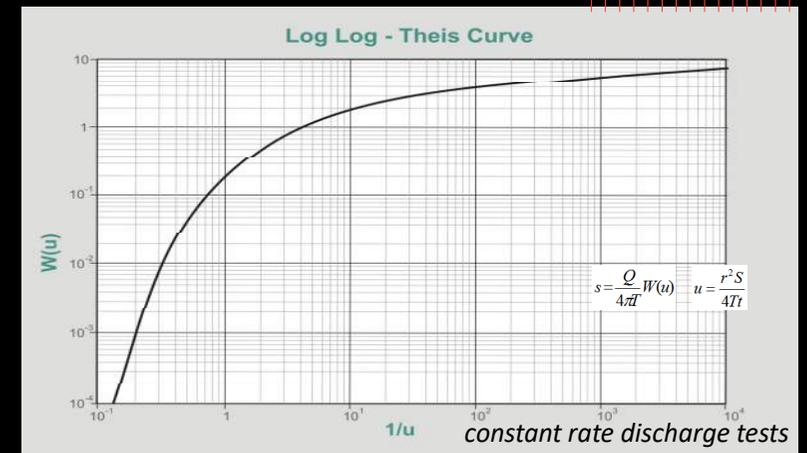
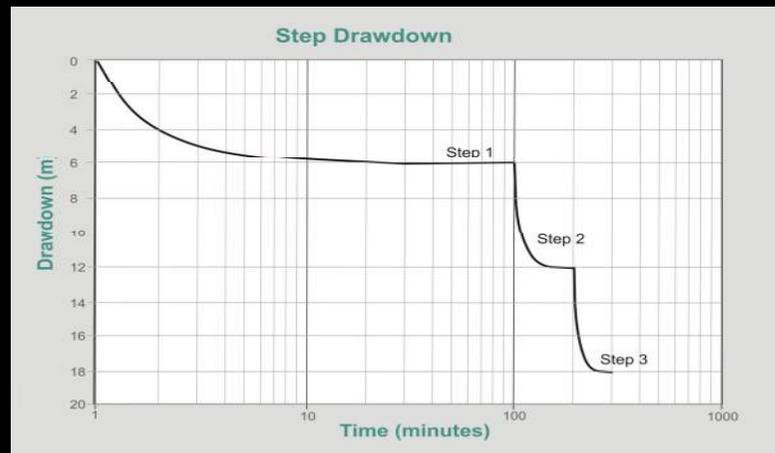
Types of aquifer discharge pumping test

- Step-drawdown test
 - Determines well efficiency.
 - Determines effective pumping rate for constant-rate pump test.
- Constant-rate pumping test
 - Single well – Transmissivity and hydraulic conductivity
 - Multi-well – Transmissivity, hydraulic conductivity, storage coefficient, verify yield of a production well
- Slug test
 - Not usually carried out for as ASR investigations
 - Not terribly reliable as really only give the aquifer properties in the immediate area around the bore hole .

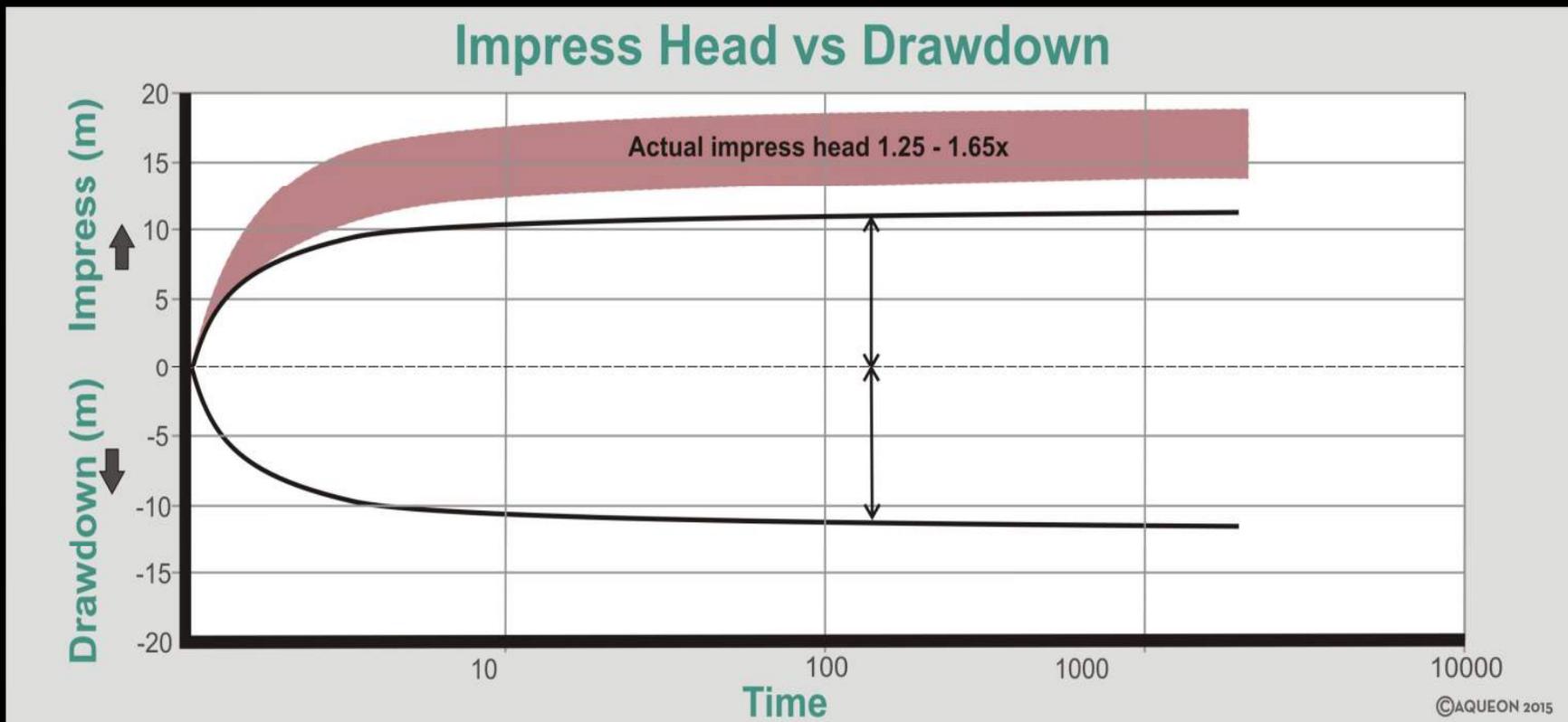


Measurements to be taken during testing

- Time (since start of test)
- Water or pressure level in the pumped bore (and any surrounding observation bores)
- Discharge rate
- Ground water quality during test (EC, pH, Eh, DO, Temperature)
- BART test kits (optional)



Impress Head

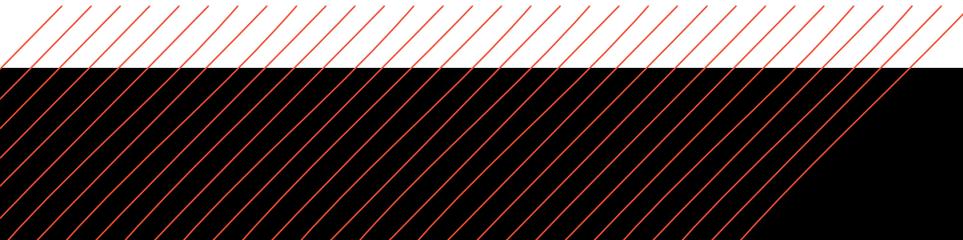


Geochemistry and MAR

- Aqueous composition of the ambient groundwater is driven by equilibrium with the aquifer matrix
- Aqueous composition of the recharge source differs from that of ambient groundwater
 - reflects origin e.g. stormwater, wastewater, stream lake, groundwater, drinking water supply, industrial effluent
 - not in equilibrium with the aquifer material
 - may be variable
 - often oxygenated, fresh
- *Geochemical processes are expected*



Pyrite mineral



10 reasons to study water quality aspects of MAR

- 1 Obtaining the licence & safeguarding public health / perception
- 2 Meeting quality regulations for infiltration and recovered water (depending on use / post-treatment)
- 3 Mapping the underground expansion of the artificial waterbody
- 4 Quantifying removal / accumulation of undesirable pollutants in aquifer (and for how long).
Behaviour of emerging pollutants
- 5 Quantifying the leaching rate of precious aquifer constituents (and for how long)
- 6 Predicting future water quality effects of MAR for adapting the intake, pre-treatment or post-treatment
- 7 Designing / Optimising MAR plants for gaining more benefits from aquifer passage (pre and post-treatment may need adaptations)
- 8 Estimating and lowering risk of chemical clogging of recovery system (by mixing different water qualities).
- 9 Optimising monitoring system: spending less and gaining better data.
- 10 Validating hydrogeological models by tracking the infiltrate and using hydrochemical patterns.

Important geochemical reactions

- Redox reactions
- Mineral equilibrium
- Cation exchange and sorption



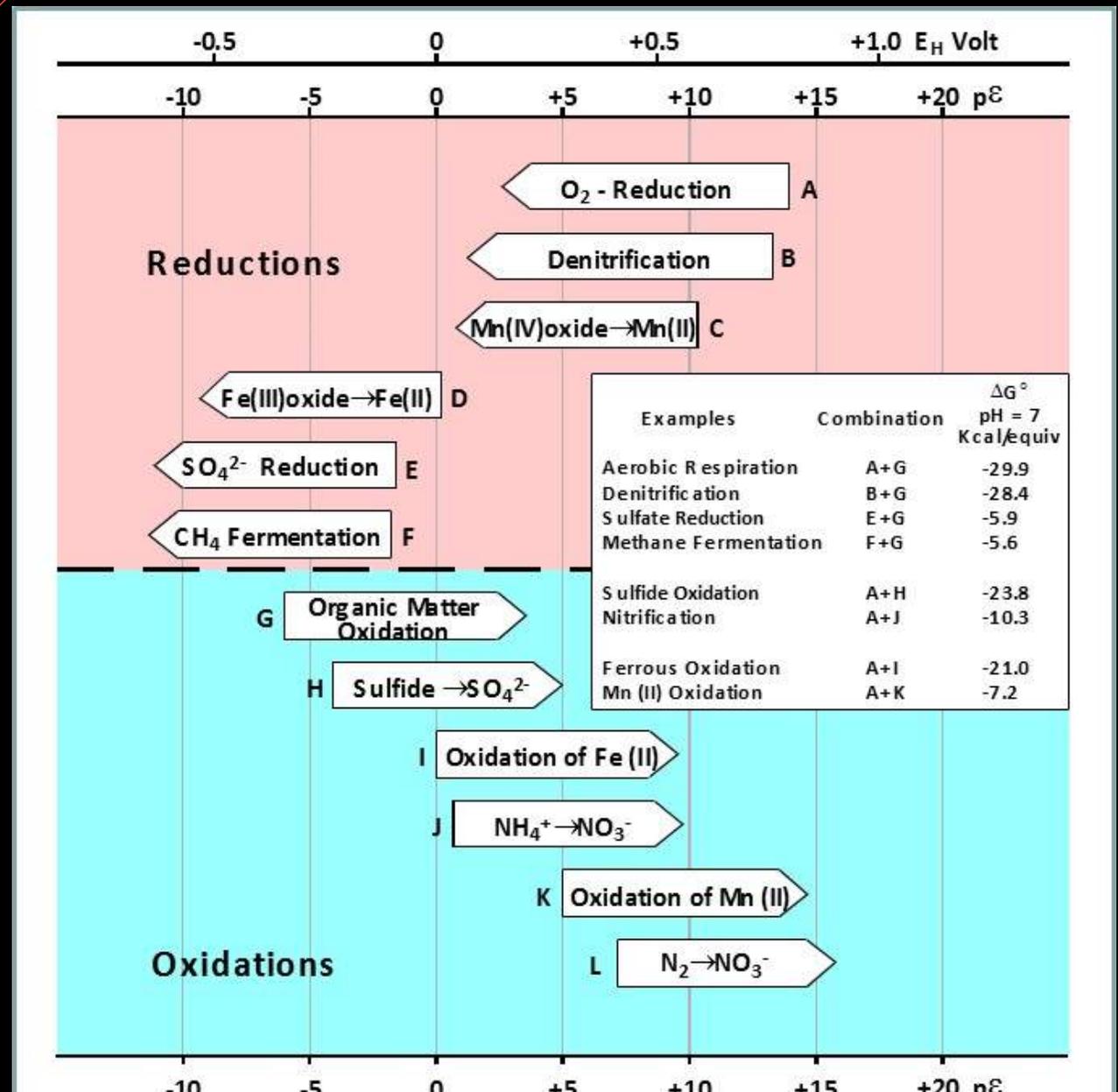
Useful References:

- *Appelo CAJ & Postma D (1999 or 2005) Geochemistry, groundwater and pollution*
- *Stumm W and Morgan JJ (1996) Aquatic Chemistry*

Redox reactions

Often microbially mediated – groundwater microorganisms gain energy through the reactions for growth & maintenance.

Reduced environment reactions and attenuation slower.

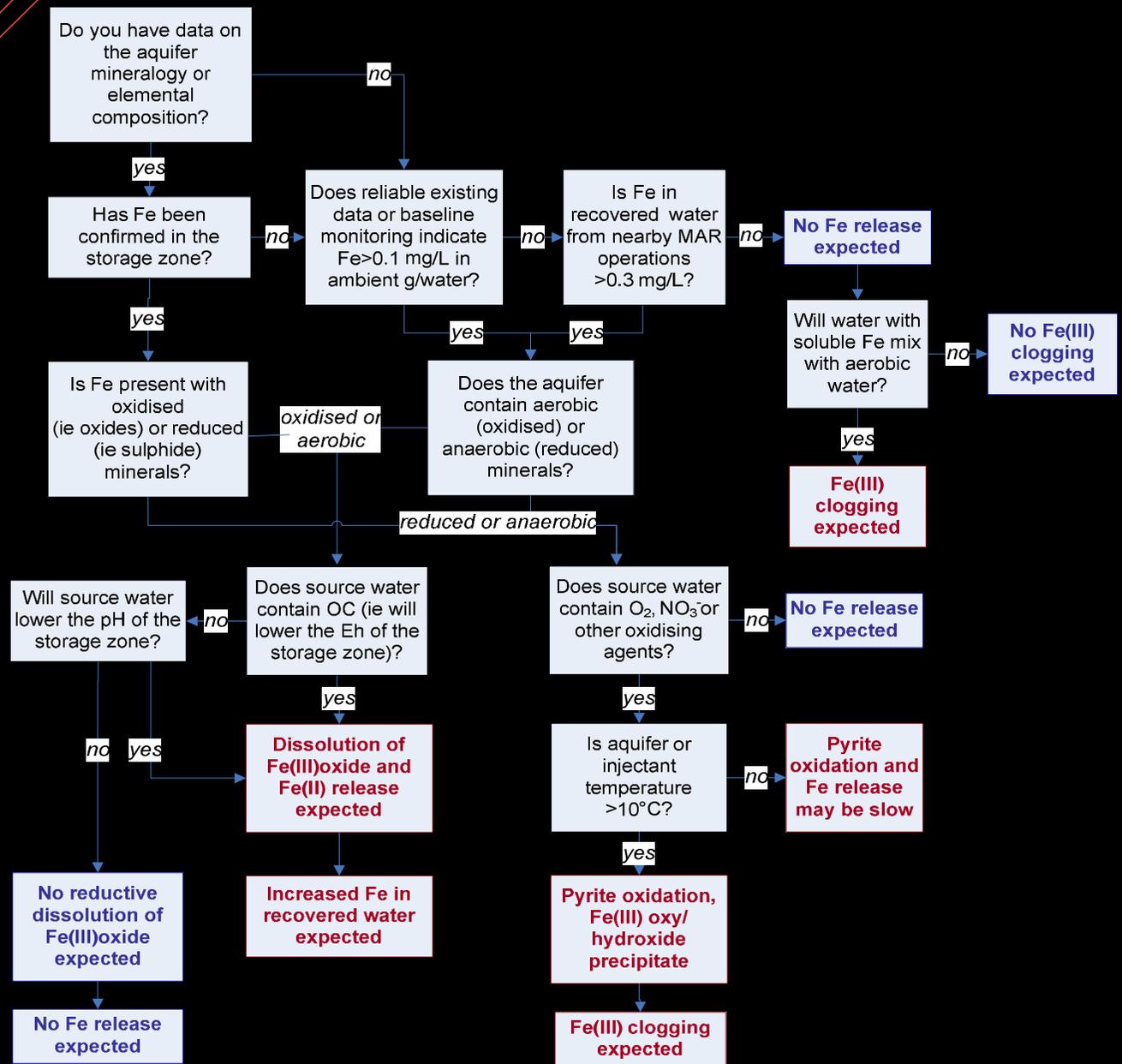


Iron mobilisation

- Full scale ASR testing in New York
- Oxygenated source water into a semi-confined, anaerobic, sand and gravel aquifer
- Pyrite confirmed in aquifer minerals
- Native groundwater Fe 0.14-0.30 mg/L
- Source water Fe 0.4 mg/L
- Temperature $\sim 15^{\circ}\text{C}$
- Recovered water Fe up to 3 mg/L (aesthetic guideline = 0.3 mg/L)
- Iron release due to oxidation of pyrite

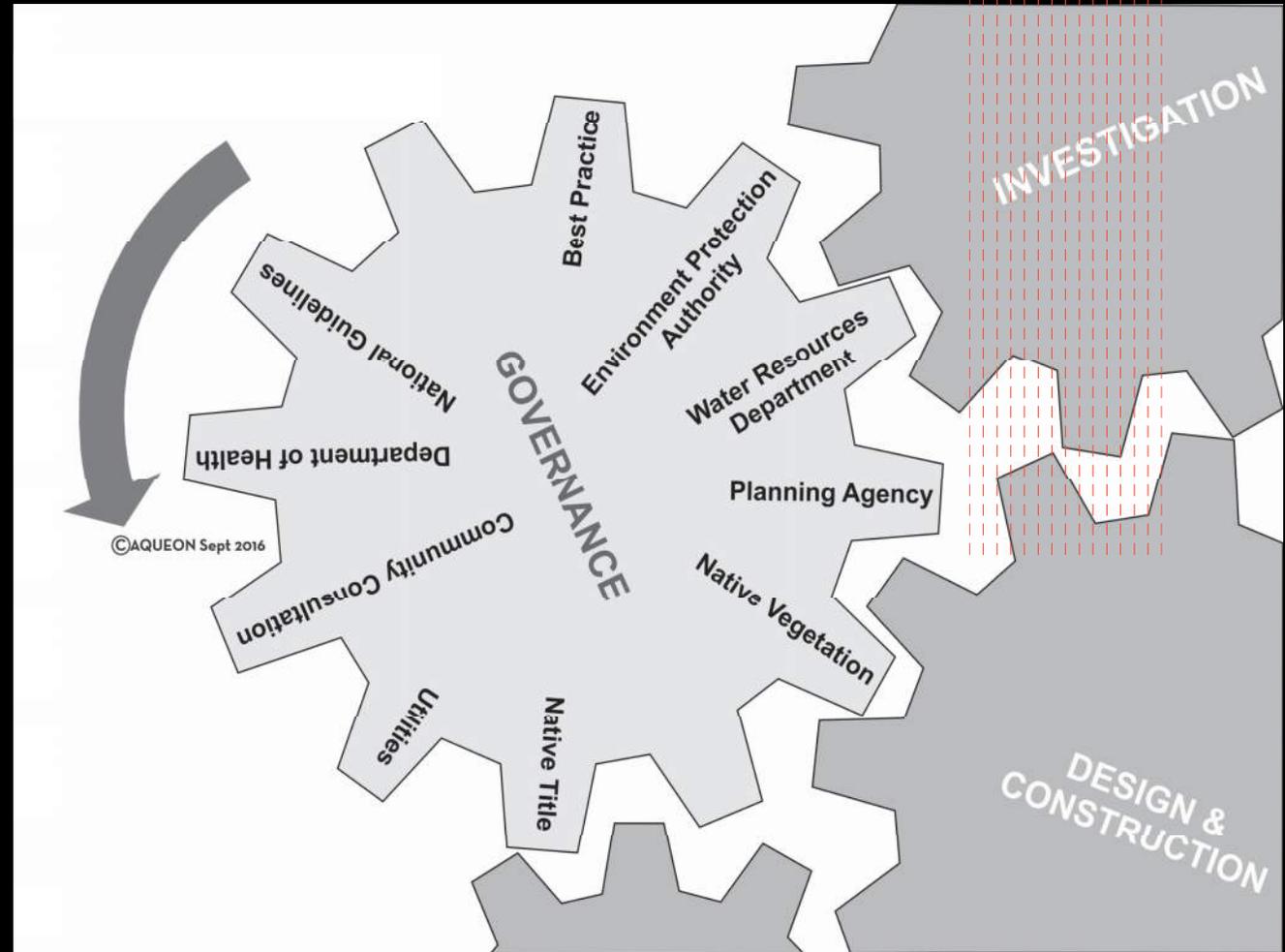


Decision support tree to identify potential for Iron mobilisation

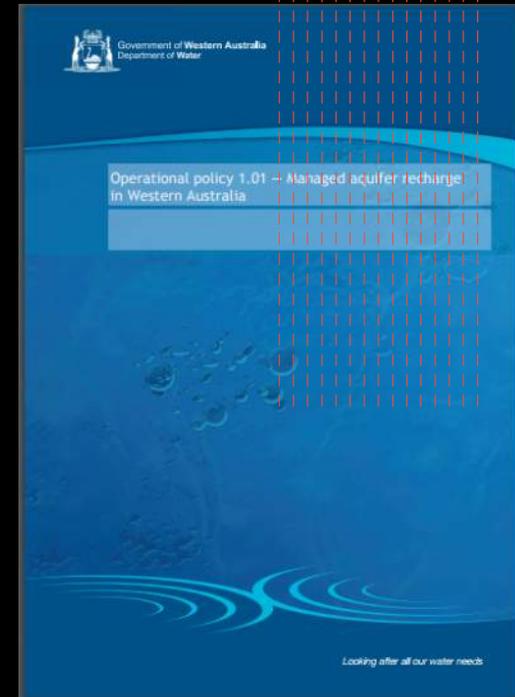
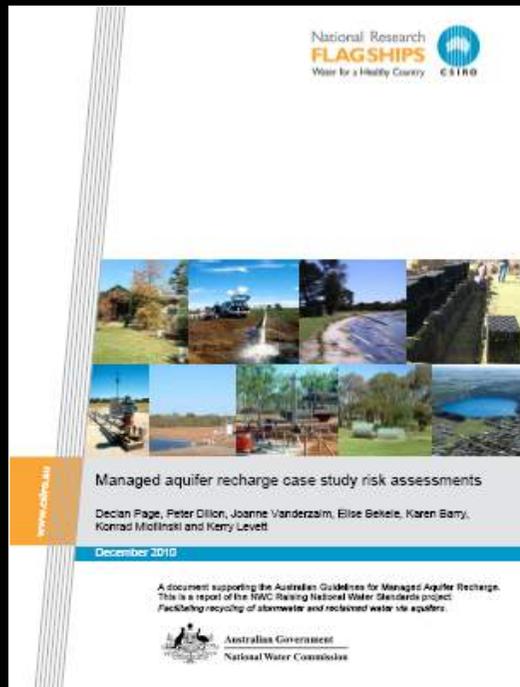
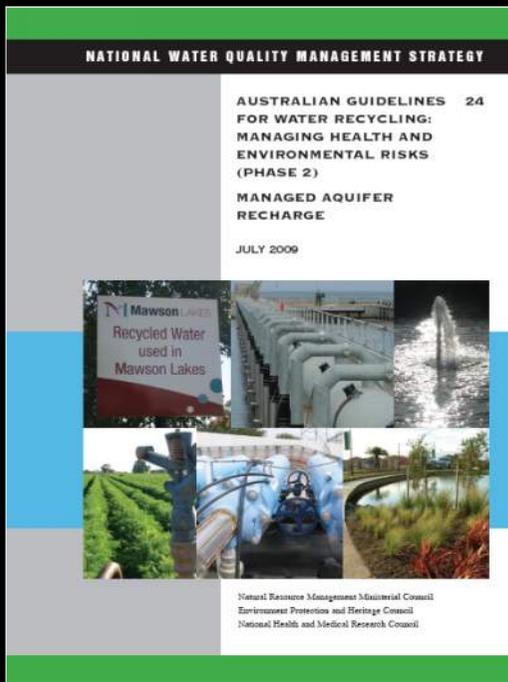


MAR Governance

- Continued liaison with the regulating authorities throughout the study is important.
- Community consultation is also a vital component of any MAR system development.
- Don't underestimate the time taken to get regulatory approval.
- Don't underestimate community input.

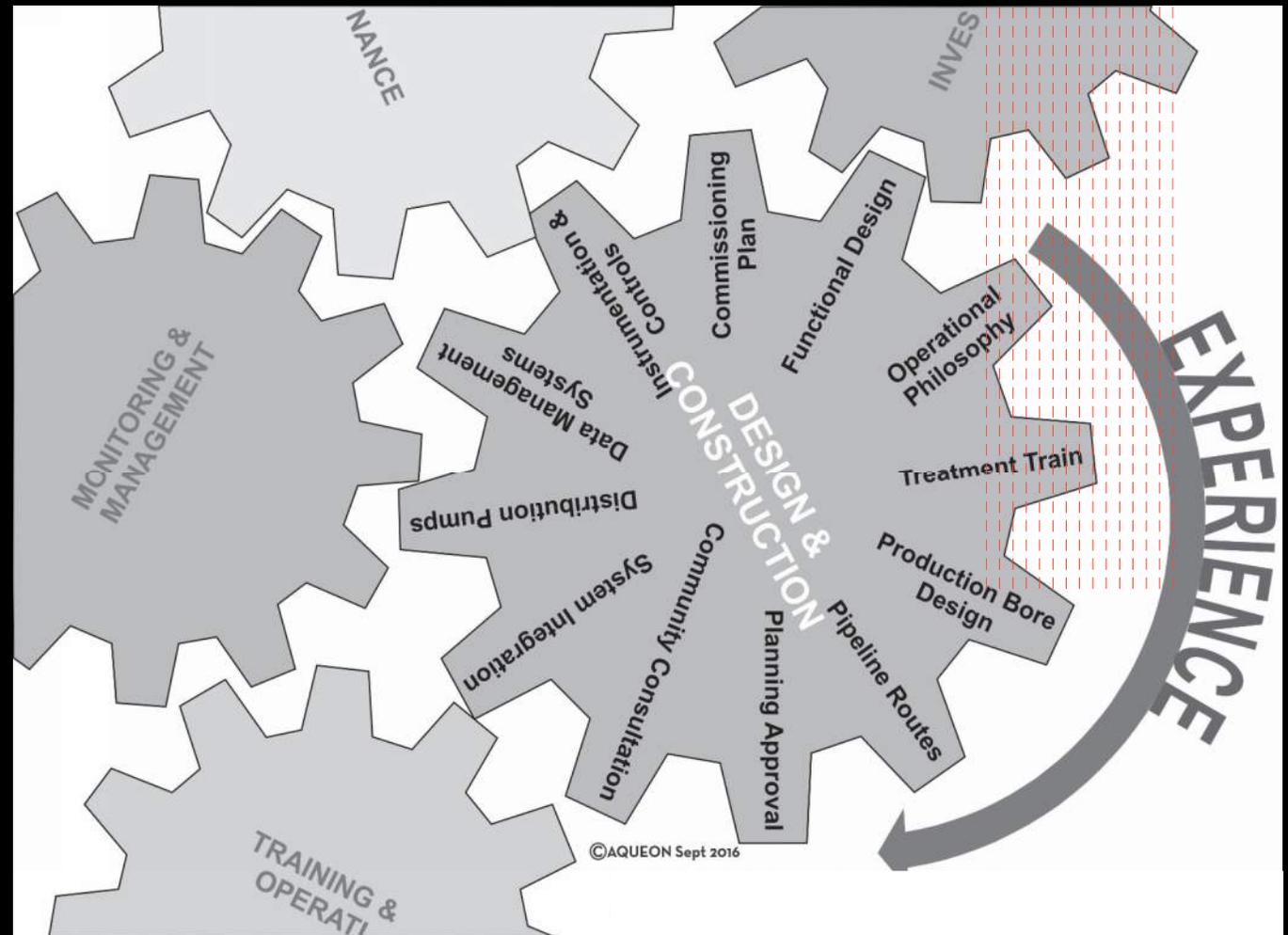


MAR Governance



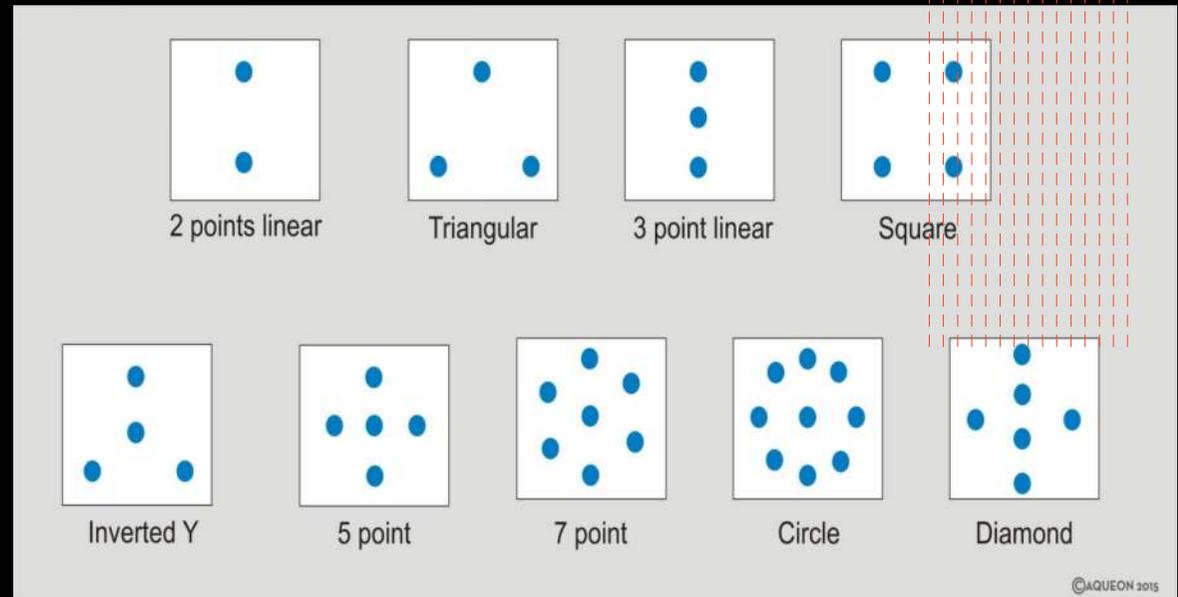
MAR Design & Construction

- Functional design
- Audit ! Using experienced independent peer reviewer
- Involve operators at each design step
- Detailed design
- Audit ! Using experienced independent peer reviewer.
- Adequate time for system commissioning

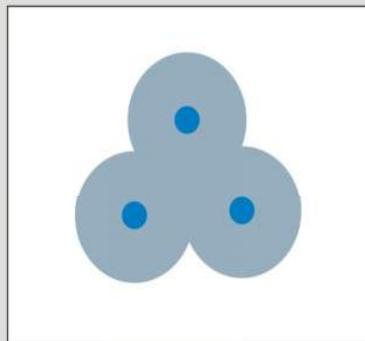


Bore field design considerations

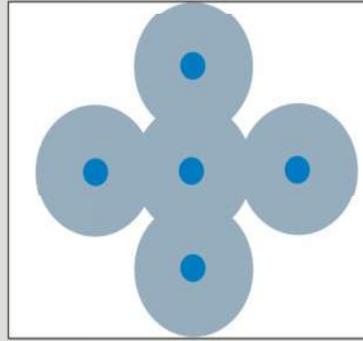
- ASR wells tend to be closer together, particularly in aquifers with poor ambient groundwater quality, to accelerate coalescence of storage plumes around each well.
- When close together greater potential for hydraulic and geochemical interference between wells.
- Need to monitor drawdown and impress head (up-coning).
- Lateral velocity of groundwater due to regional gradients or well interference.



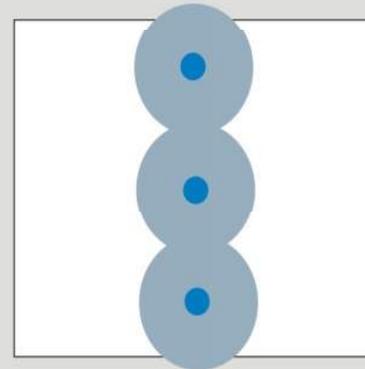
Bore field layout plume extent



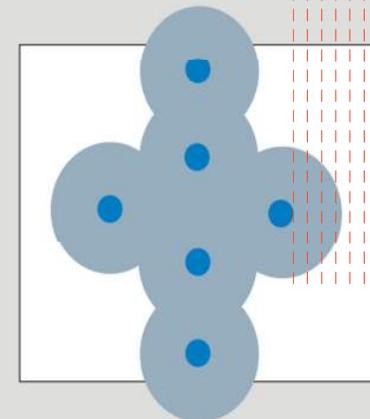
Triangular



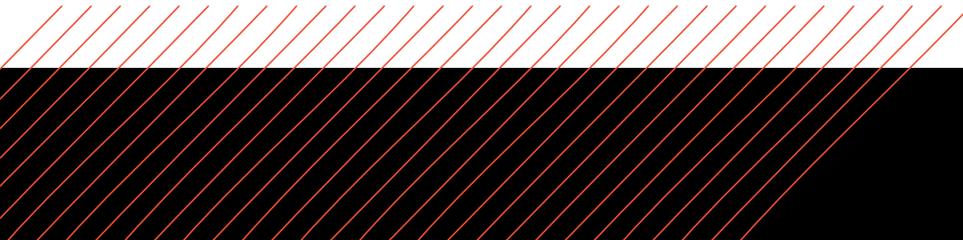
5 point



3 point linear



Diamond



Pump selection

Submersible

- Noise unlikely to be a problem
- Requires plant enclosure up to 3 m high
- Lower cost than turbine
- Power consumption higher than turbine
- Require more maintenance as motor fully submerged
- Greater space required within the intake chamber
- Access for maintenance is difficult

Turbine

- More efficient than submersible
- Maintenance on pump head easier due to dry access
- Requires long vertical shaft (time to install & remove)
- Intake chamber size is reduced compared to submersibles
- Capable of operating at great depths
- More tolerant of sand production
- Higher cost than submersible pumps
- More time consuming to retrieve intake and replace impellers

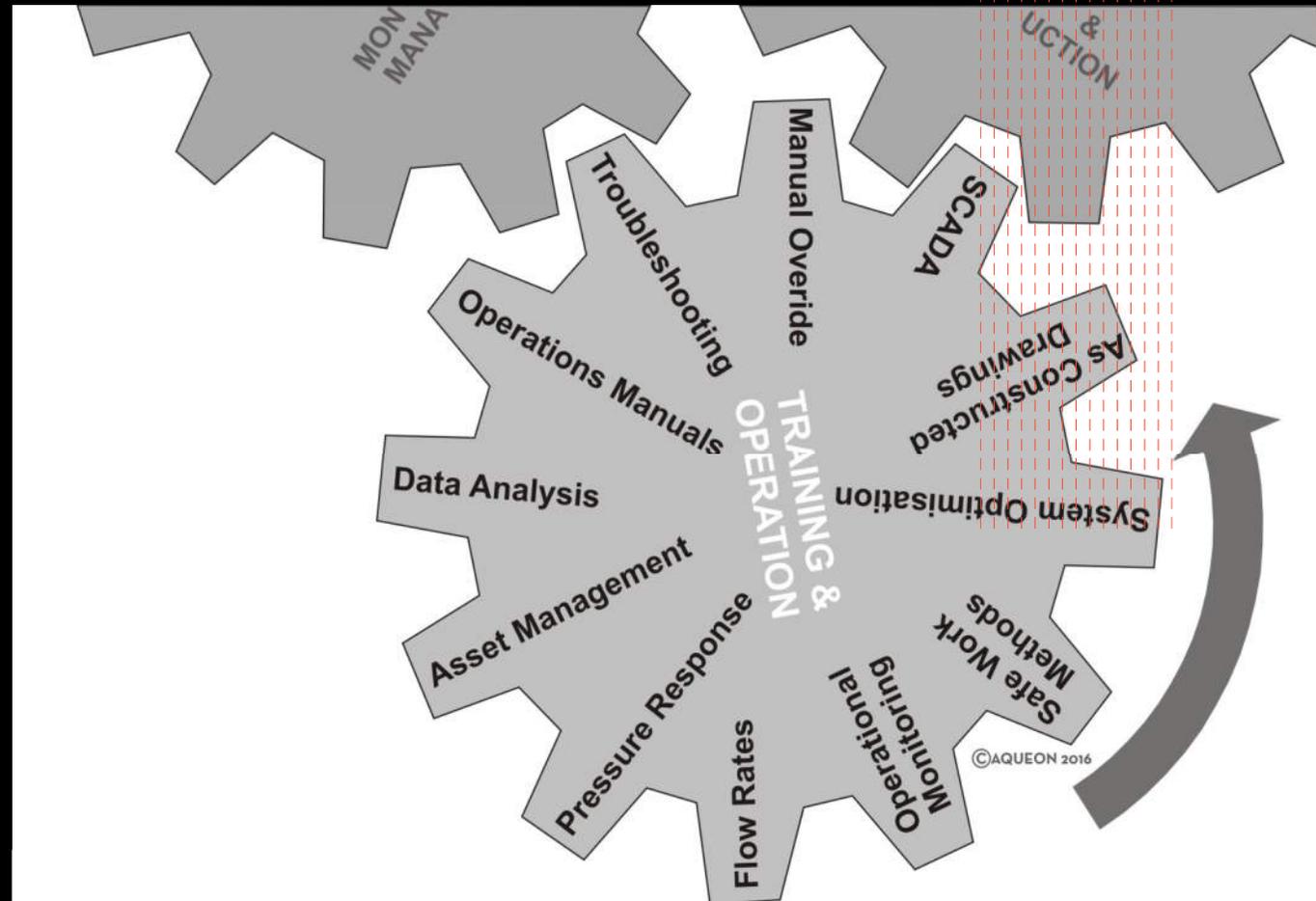
Downhole flow control valve

- Non-adjustable downhole flow control.
 - Injection tubes single or multiple (need to maintain a solid column of water to prevent air clogging)
 - Annulus flow
 - Pump column flow
 - Vacuum recharge (USA)
 - Packer assembly for well shut in
- Need to handle air volume in pump column, where standing water level is deep therefore risk of clogging due to air entrainment (gas binding) is high.
 - Use down hole flow control valves
 - available from various suppliers but are expensive



MAR Training & Operations

- Adequate documentation prepared with the support of operations staff.



Instrumentation – Programmable Logic Control (PLC)

- Brains/computer that runs the system locally
- Operators must be familiar with these systems

Network
Switch

24V Power

Serial

CPU

IO Modules



Instrumentation – Human Machine Interface (HMI)

- A local robust IP rated touch screen that interfaces directly to the PLC
- Give local control and monitoring at the site
- Recommend a minimum size of 10 inch for effective control of ASR/MAR schemes.



Source: APC Integration

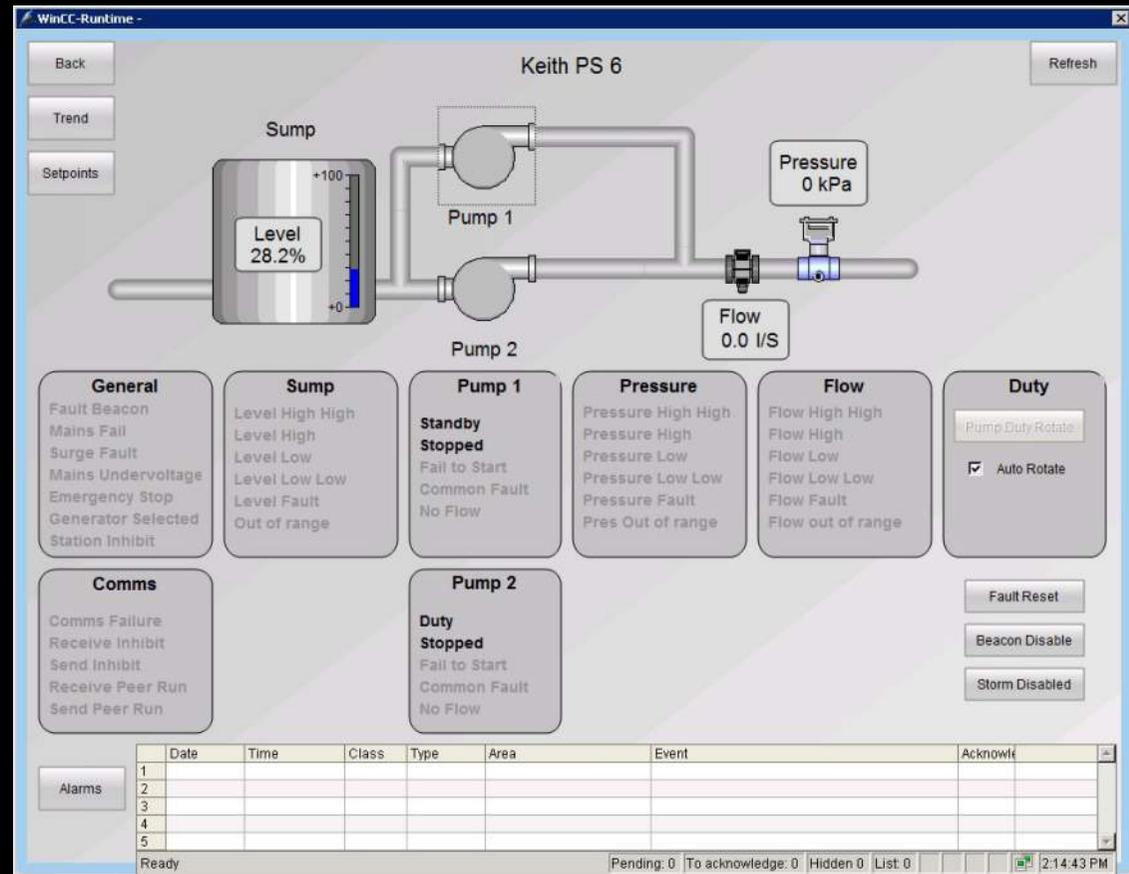
Instrumentation – VFD or VSD

- Allows control of the pumping speed
- Can be used to control pressure and flow.
- Need to be oversized for inefficient bore pumps
- Can cause issues (“hunting”) when running multiple bores



Instrumentation – Supervisory Control and Data Acquisition (SCADA)

- Ties everything together.
- Allows for remote operator control.
- Central point where all the data of the:
 - respective sites can be collected, stored,
 - monitored and displayed.
- Reduces field site inspections.
- Assists with complying with the EPA.
- Needs to run on a computer somewhere.



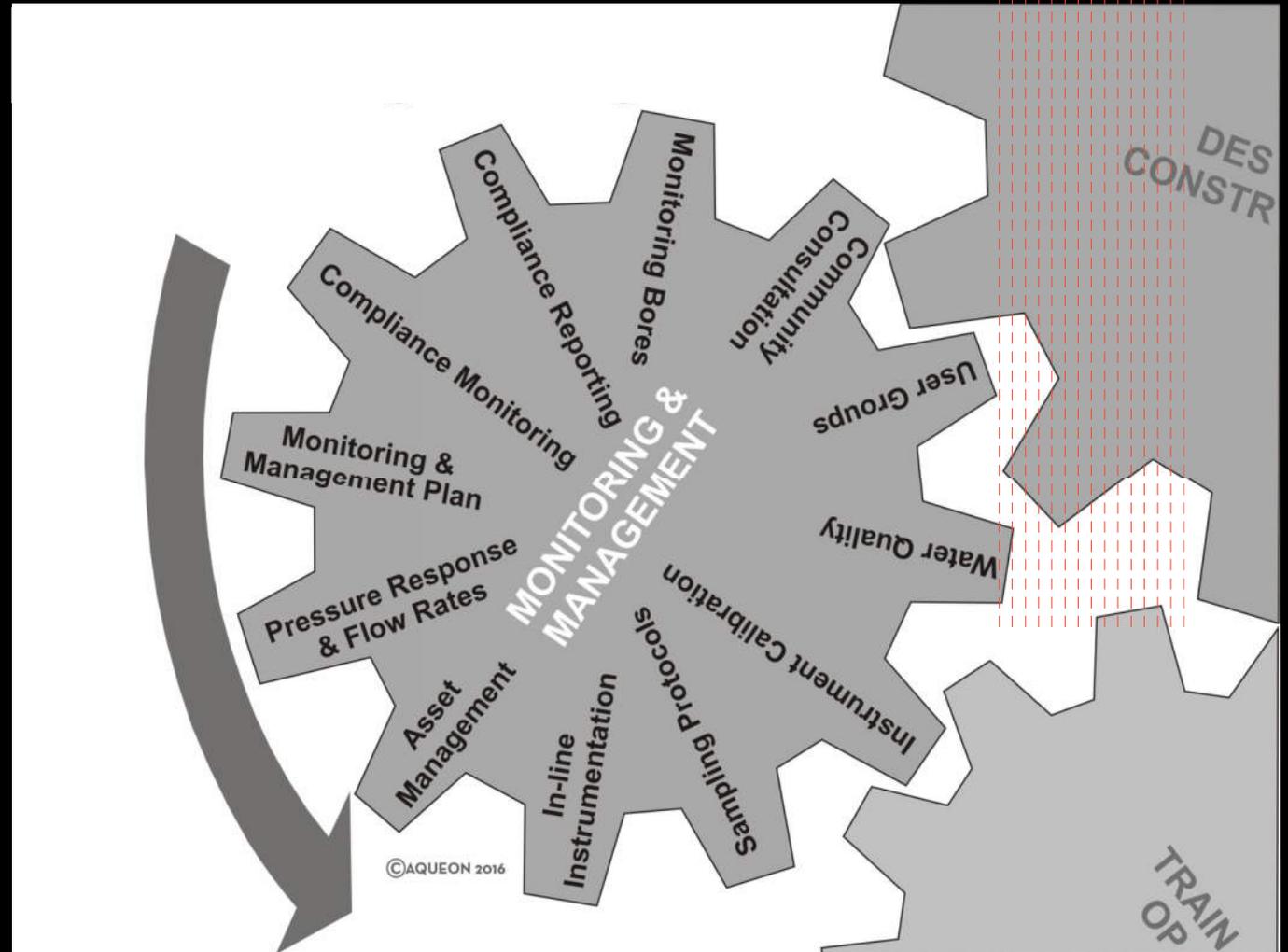
Data Management and Network

- Network – Connects the system together
 - Ethernet – For short local connections
 - Fibre communications/loops for connections longer than 100m
 - Wireless Telemetry – line of sight radio links for up to 20km
 - 3G or Next G – using the existing telecommunications infrastructure – initial lower cost?
 - Vital for collection of data to a single point



MAR Monitoring & Management

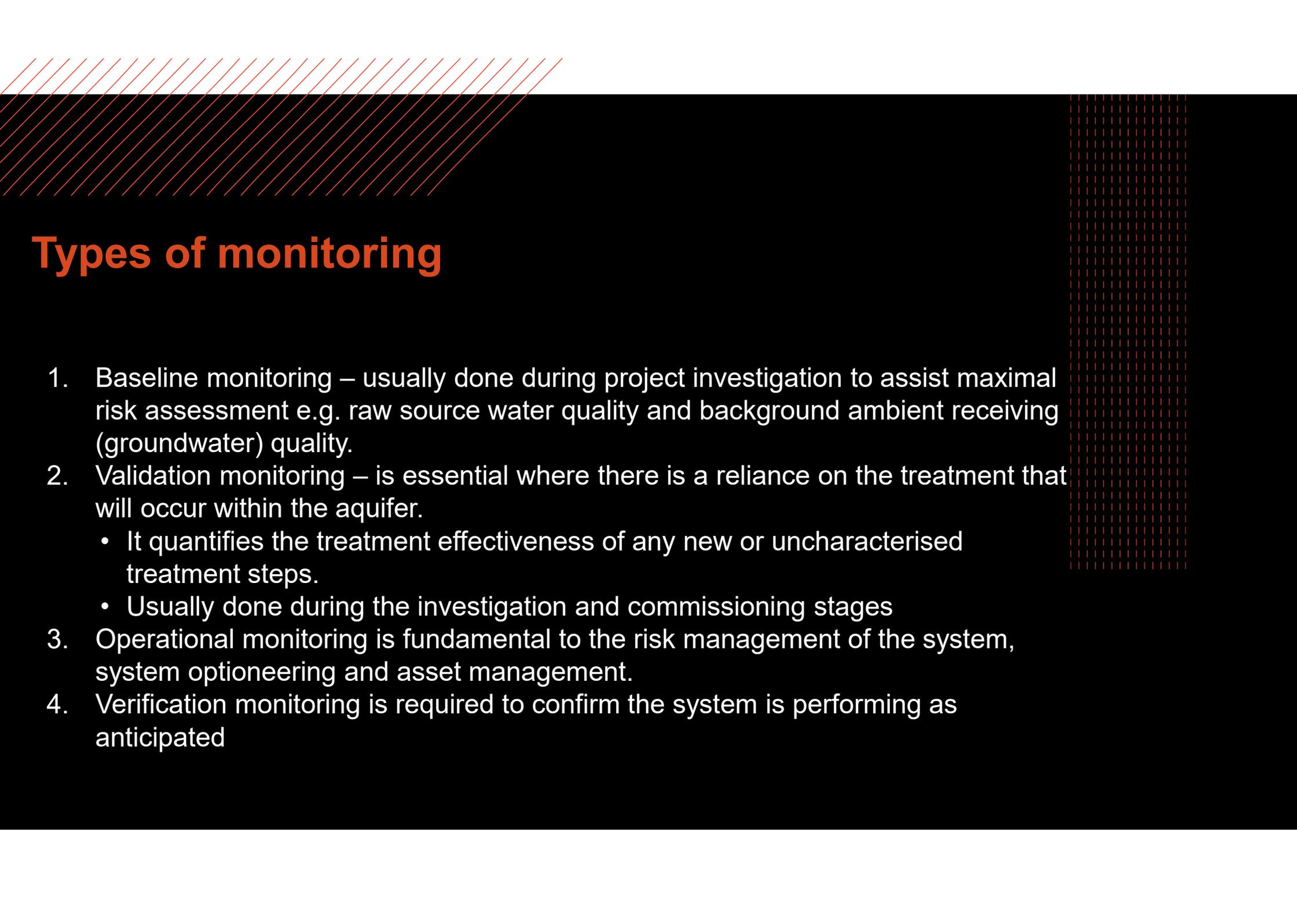
- Operational monitoring
- Compliance monitoring
- Verification monitoring
- System optimisation



Why monitor ?

- Achieve optimum operation and reduce lost harvest opportunities
- Asset management and effective maintenance
- Maintenance planning
- Regulatory compliance





Types of monitoring

1. Baseline monitoring – usually done during project investigation to assist maximal risk assessment e.g. raw source water quality and background ambient receiving (groundwater) quality.
2. Validation monitoring – is essential where there is a reliance on the treatment that will occur within the aquifer.
 - It quantifies the treatment effectiveness of any new or uncharacterised treatment steps.
 - Usually done during the investigation and commissioning stages
3. Operational monitoring is fundamental to the risk management of the system, system optioneering and asset management.
4. Verification monitoring is required to confirm the system is performing as anticipated

Operational monitoring

- Operational monitoring is essential to aid in setting appropriate critical limits such as:
 - Shutting down recharge due to poor quality source water
 - Shutting down recovery due to quality limits being reached or exceeded
 - Instigating remediation steps such as backwashing
 - Changing dose concentrations in pre-treatment processes
- Operational monitoring is essential for asset management, system optioneering and validation of any process or equipment changes.
- Operational monitoring includes both on-line instrumentation and visual inspections of infrastructure.



Verification monitoring

- Verification monitoring should be a subset of operational monitoring.
- Is conducted to meet compliance requirements to enable regulating agencies to assess the whole of the MAR system.
 - The system is operating within licence conditions
 - The system is operating as predicted
 - Changes and modifications to the system are captured



What to monitor?

- Rainfall
- Waterways
- Wetlands
- Source water quality & treatment
- Aquifer response to both injection and extraction.
- Distribution network.
- The monitoring framework (water quality) should be volume based not time based and structured around identified quality risks to the receiving environment or existing third party users.
- As much as possible monitoring should be real time, pressure, flow rates, volumes, quality (EC, Turbidity, pH)



WGA

WALLBRIDGE GILBERT
AZTEC

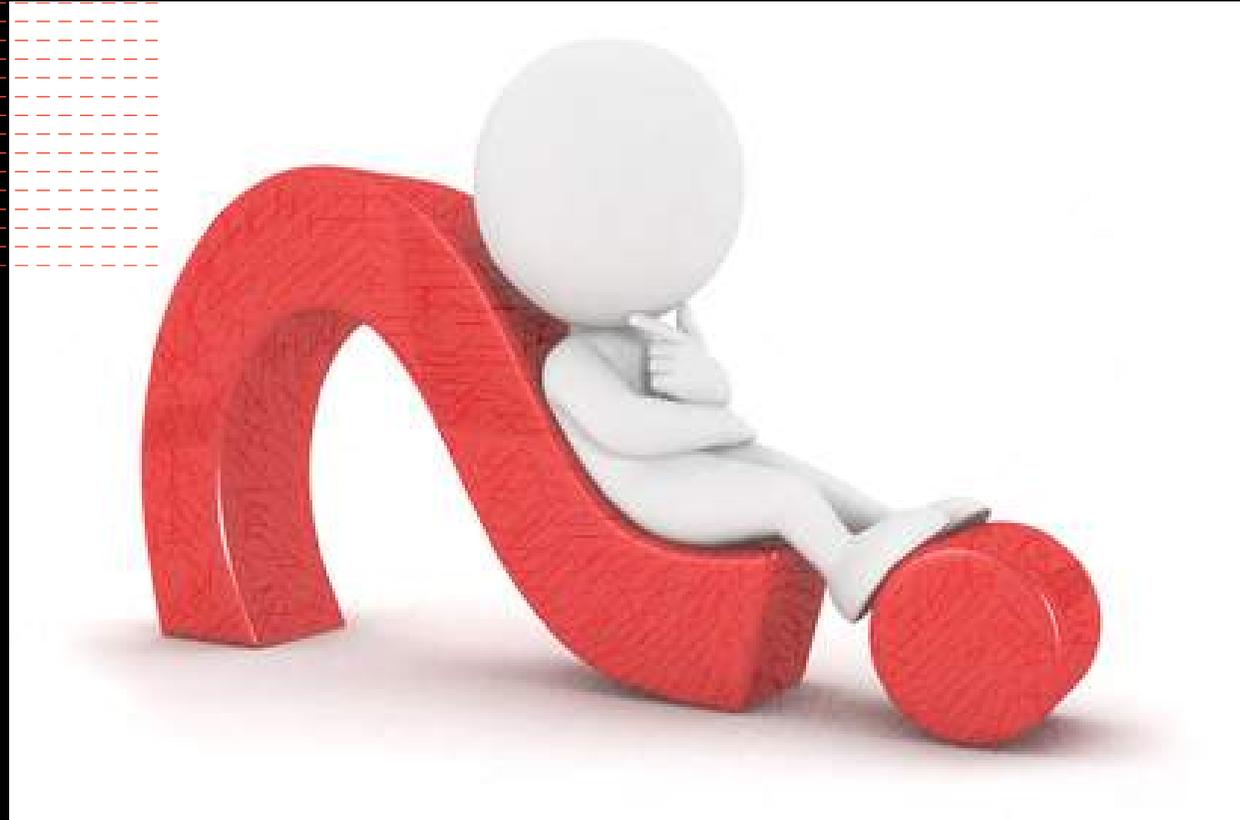
Questions

ADELAIDE

60 Wyatt Street
South Australia 5000
Telephone: +61 8 8223 7433

WALLBRIDGE GILBERT AZTEC

www.wga.com.au



Infiltration pits and galleries - including their possible use in Perry Lakes



Floreat
Infiltration
Galleries

Perry Lakes

Managed Aquifer Recharge and Recycling Options (MARRO)



Dr Don McFarlane, Adjunct Professor
School of Agriculture and Environment
University of Western Australia

MAR Essentials
Workshop
Perth

26th October 2017

The talk will cover

- Infiltration galleries and pits
- Floreat Infiltration Galleries
- MARRO project
- Possible application at Perry Lakes
- Infiltration pits at Gordon Road and Halls Head WWTPs
- Conclusions

Infiltration into Swan Coastal Plain

Source: Davies, JR, Rogers, AD, Bott, D and Barnett, JC (2016) How many holes does one soakwell need? 2016 IPWEA State Conference



J6130e 1 March 2016 1

//



1200 dia x 1200mm
deep soakwell, 1.4 m³

Tunnelwell; 1.4 m³

Inside view of a tunnelwell

- 15m³ of water discharged into the soakwell (with either blocked and 'open' bases) and Tunnelwell into 2.5m deep sand over coffee rock over 4-5 hrs
- Shallow groundwater levels rose 60-80cm when measured 2m from devices
- Another test added a 10 year ARI 12 hour duration storm (5.5mm/h = 66 mm storm) to a house on Bassendean Sands and produced zero runoff (JDA 2015)

Source: Davies JR (2015). Rivergums, Baldivis: Rainfall runoff testing. Consultant report

Kwinana WWTP infiltration basins

Started in 1975 with infiltration initially onto a dunal swale
Limited maintenance required – bob cat to remove solids, especially algae which grows because of access to light and nutrient-rich water



Area: 0.96 ha

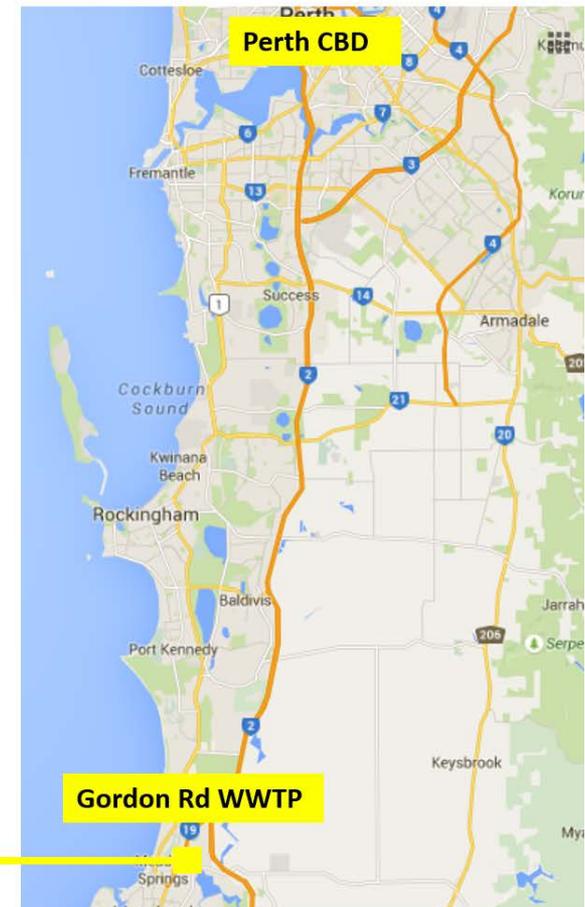
Approx. depth: 4.0 m

Operated in pairs (N and S)

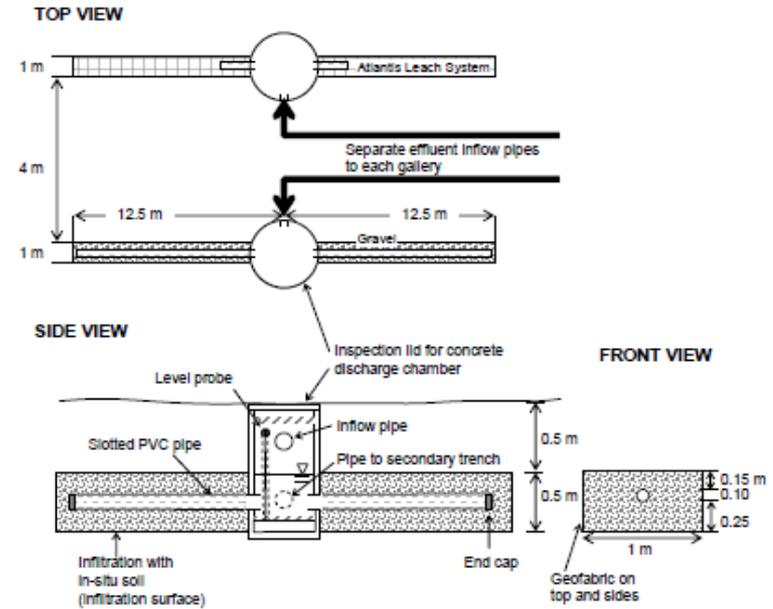
1.7 GL/y

Gordon Road WWTP

Started in early 1970s - now 3.5 GL/y
Largest example of treated wastewater disposal to land in Perth-Peel region



Floreat Infiltration Galleries



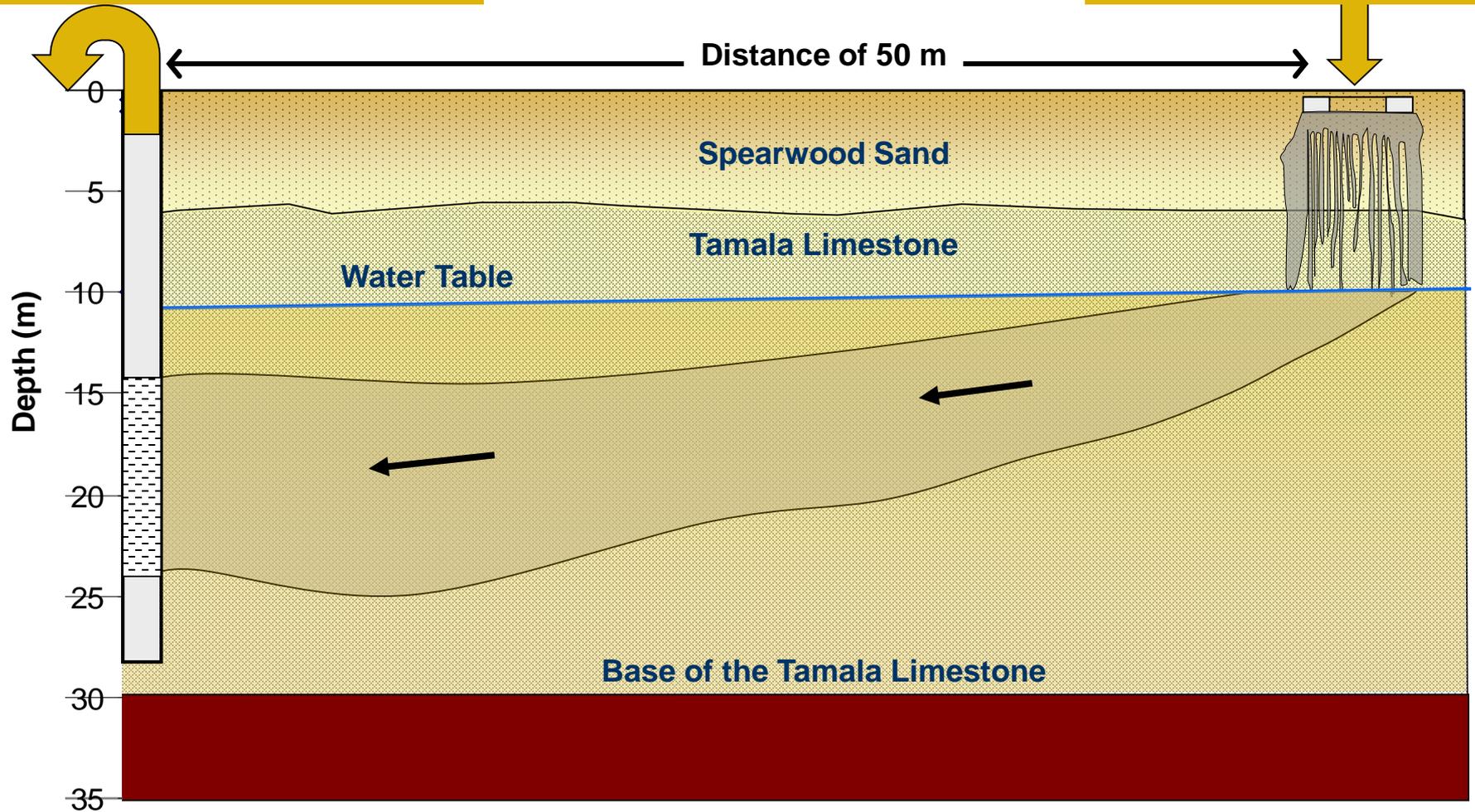
Managed aquifer recharge at the Floreat Infiltration Gallery site

Five fold recovery from 50m results in 70 day residence time

(Source: Elise Bekele, CSIRO)

**Groundwater + Effluent
Pumped to Sewer
(250 KL/day)**

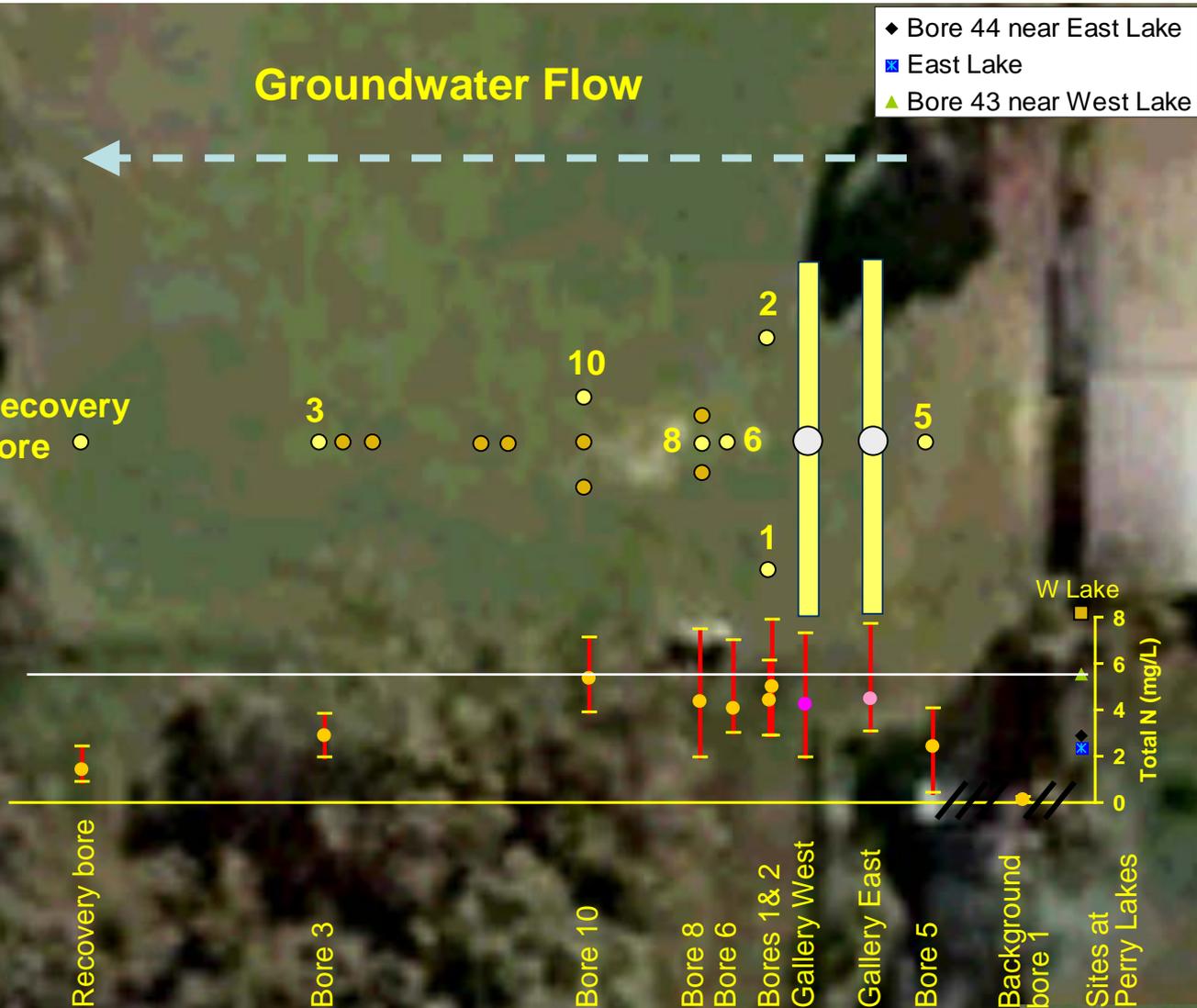
**Treated Sewage Effluent
(50 KL/day)
Inflow**



Floreat Infiltration Galleries – Groundwater Quality

Data from Oct. 2005 to Dec. 2006 (Source: Elise Bekele, CSIRO)

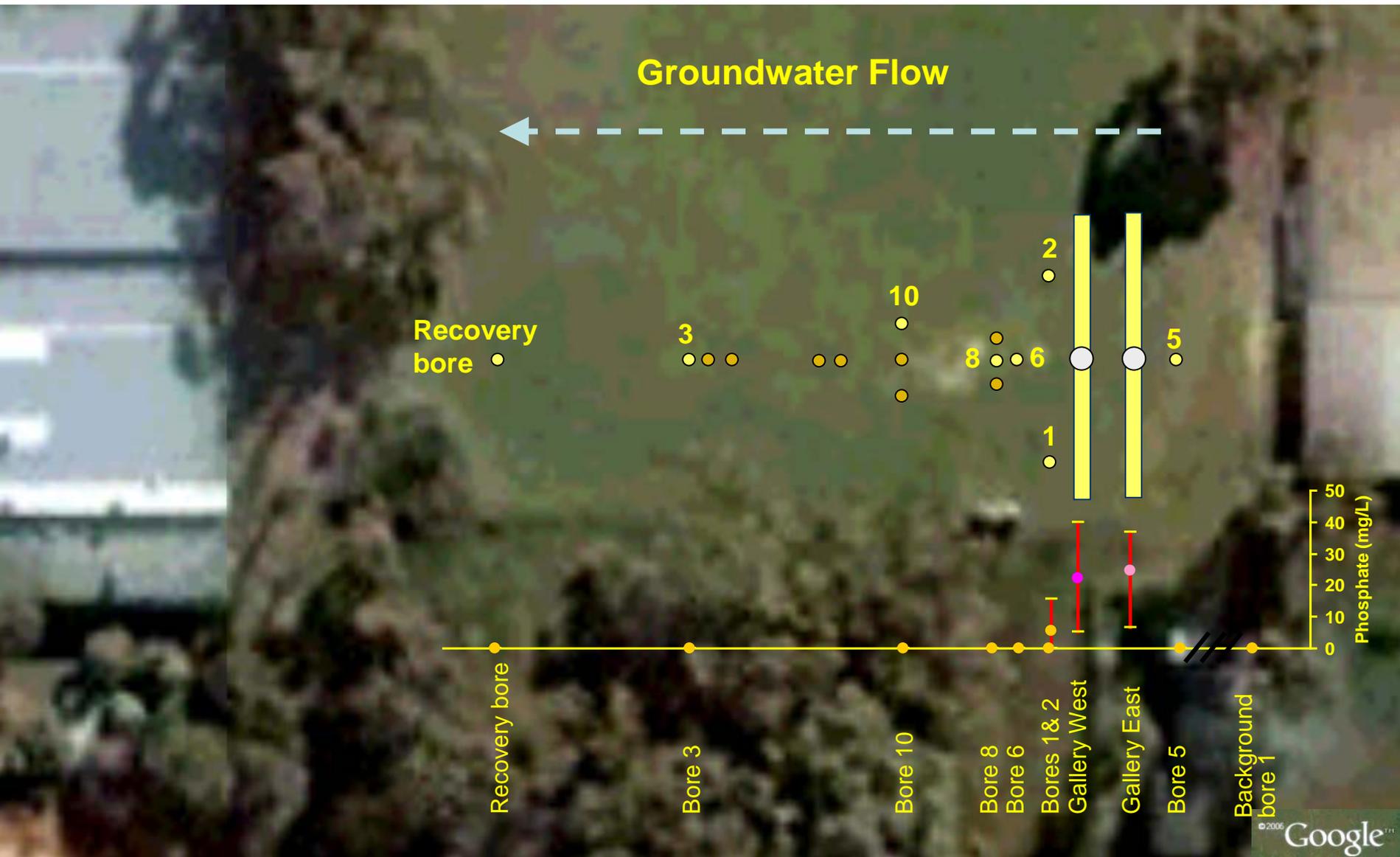
Total Nitrogen



Floreat Infiltration Galleries – Groundwater Quality

Data from Oct. 2005 to Dec. 2006 (Source: Elise Bekele, CSIRO)

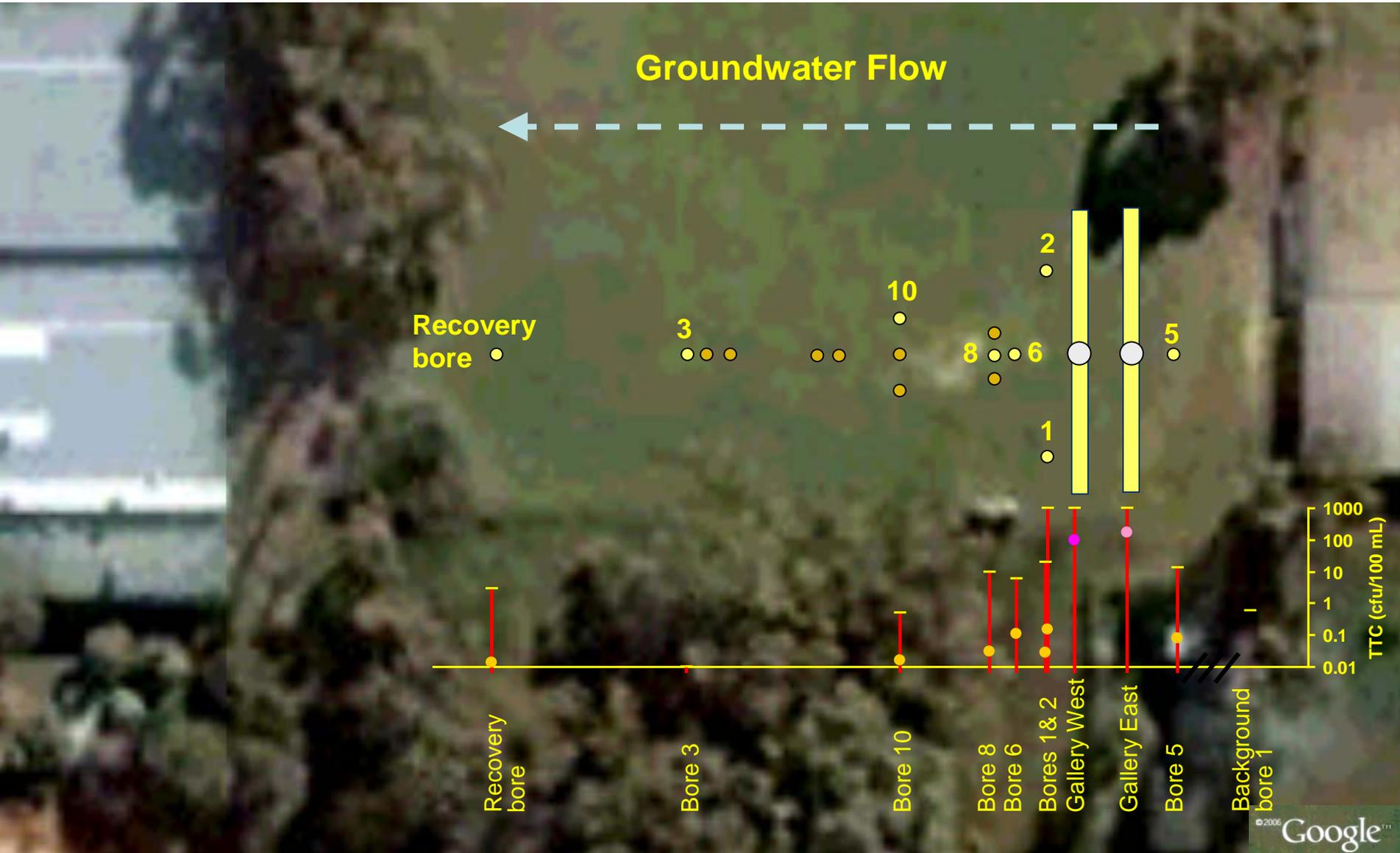
Phosphate



Floreat Infiltration Galleries – Groundwater Quality

Thermotolerant coliforms

Data from Oct. 2005 to Dec. 2006 (Source: Elise Bekele, CSIRO)



Water quality statistics for treated wastewater, after passage through the aquifer and within Perry Lakes

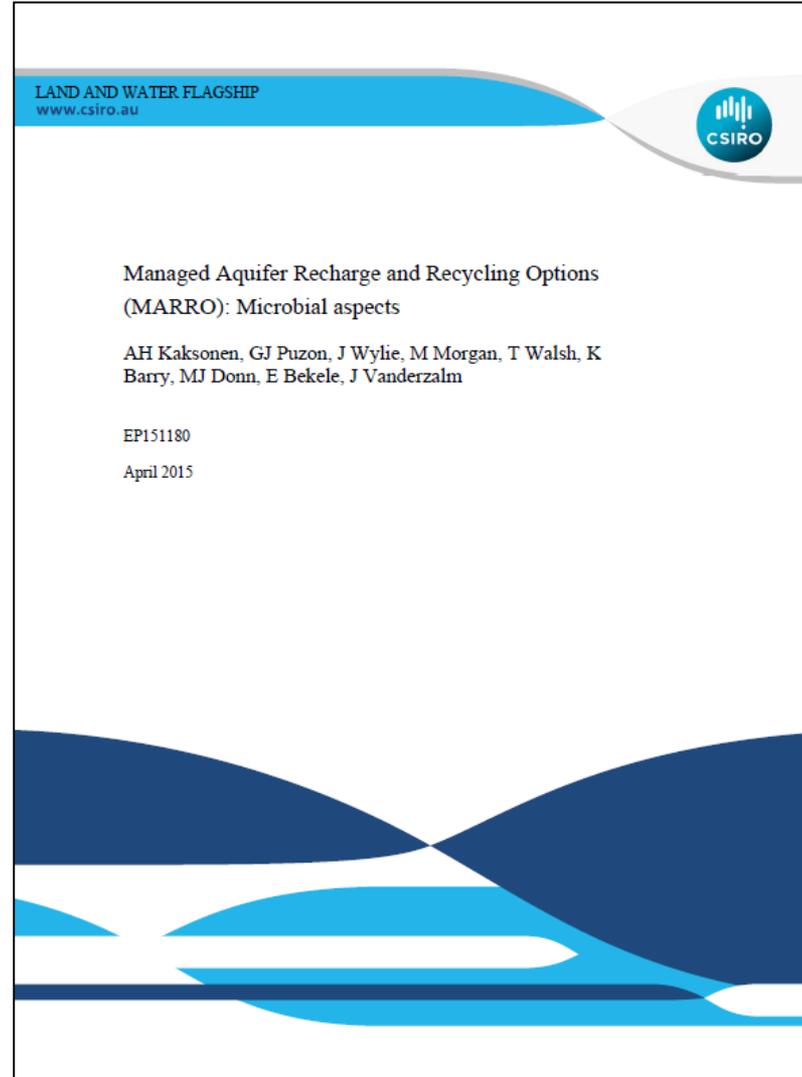
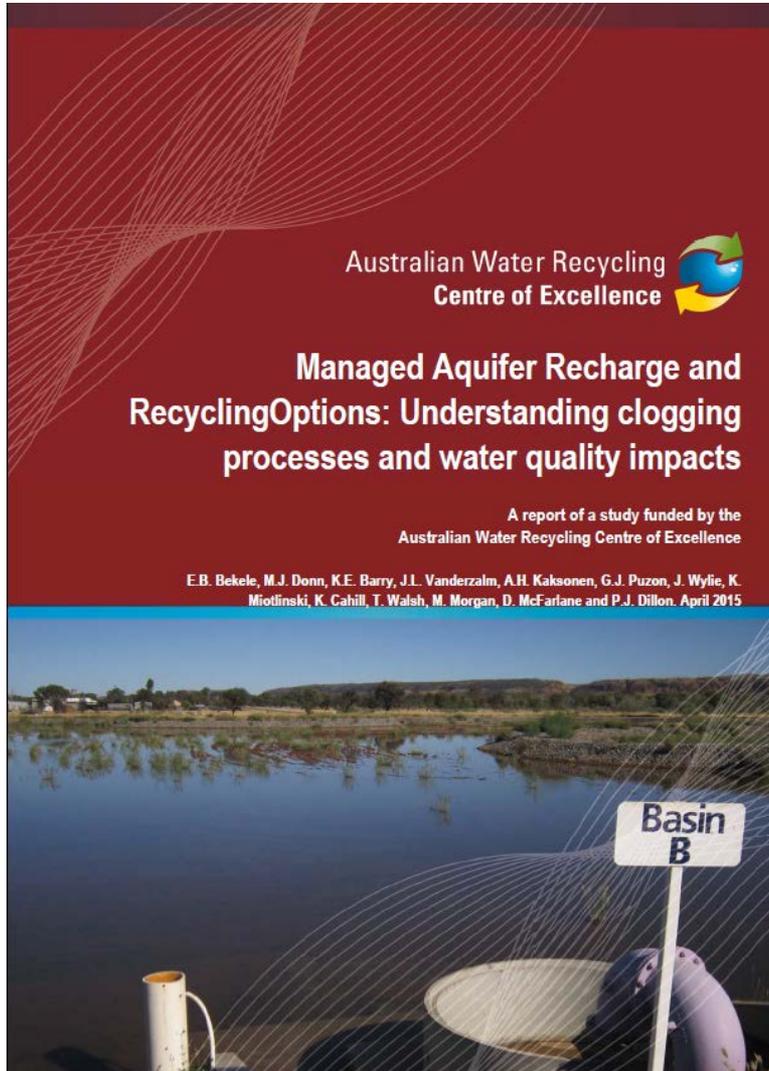
Parameter	Treated wastewater to FIG (mean and range)	FIG recovery bore (mean and range)	Perry Lakes groundwater bores (mean and range)
Total dissolved solids (mg/L)	755 540 to 1,200	681 660 to 720	951 663 to 1586
Total nitrogen (mg/L)	4 2 to 8	1.4 0.86 to 2.4	1.9 0.5 to 4.8
Phosphate (mg/L)	23 5 to 40	0.03 <0.03 to 0.03	0.14 0 to 0.4
Thermotolerant coliforms (cfu/100mL)	120	0.01	

- Similar salinity ranges mean infiltrated water should mix
- N ranges overlap but wastewater is double Total N what is in the lakes
- P is high but removed by Tamala Limestone aquifer (FIG, Gordon Road and Halls Head experience)
- Thermotolerant coliforms are removed quickly in the aquifer (FIG and Halls Head experience)
- Trace organics should be removed under these conditions (S. Toze data not shown)

Source: Adapted from McFarlane, D.J., Smith, A., Bekele, E., Simpson, J. and Tapsuwan, S. (2009). Using treated wastewater to save wetlands affected by climate change and pumping. *Water Science and Technology* 59(2): 213-221S

MAR and Recycling Options (MARRO) project

Source: CSIRO reports (2015) shown below



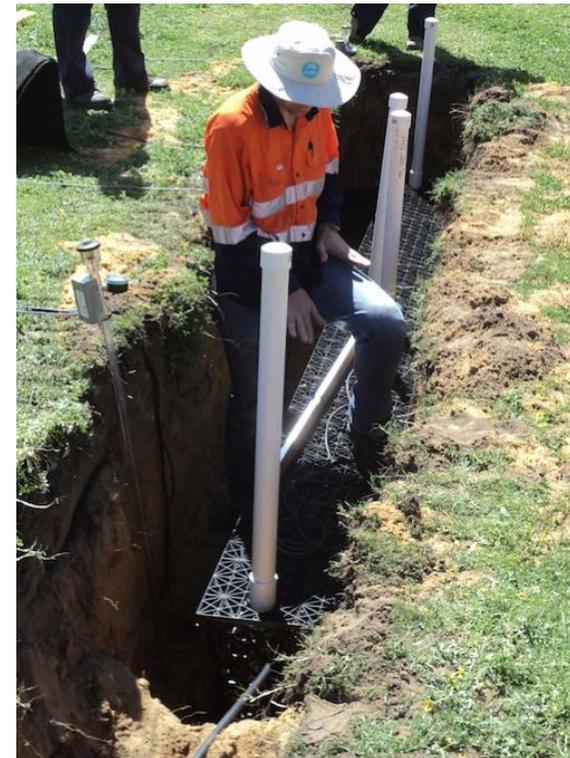
MARRO results

Soil column infiltration experiments

- Issues with method makes results unrealistic to extrapolate to the field
- Particulates trapped and biofilm = early clogging
- Limited N and P removal occurred in the soil

Floreat field experiment

- Secondary treated wastewater can be infiltrated at relatively high recharge rates (4 m/d);
 - TSS below a target level (e.g. 5 mg/L) will reduce the potential for clogging;
 - Periodic drying of the galleries may reduce clogging problems
- Heterogeneous clogging developed locally below the gallery and increased lateral flow of wastewater
- Clogging layer was composed of biofilm, roots and solids
- In Spearwood Sand, large reductions in phosphate and dissolved organic carbon can be expected
- The reduction will depend on the recharge rate relative to the rates of biodegradation and sorption
- Results were similar to the Floreat Infiltration Gallery but at higher infiltration rates (4 versus 1 m/day)



MAR proposals for Perry Lakes

1992 – present (3 attempts to date)



Weed
invasion



Completing a
detailed bore
network

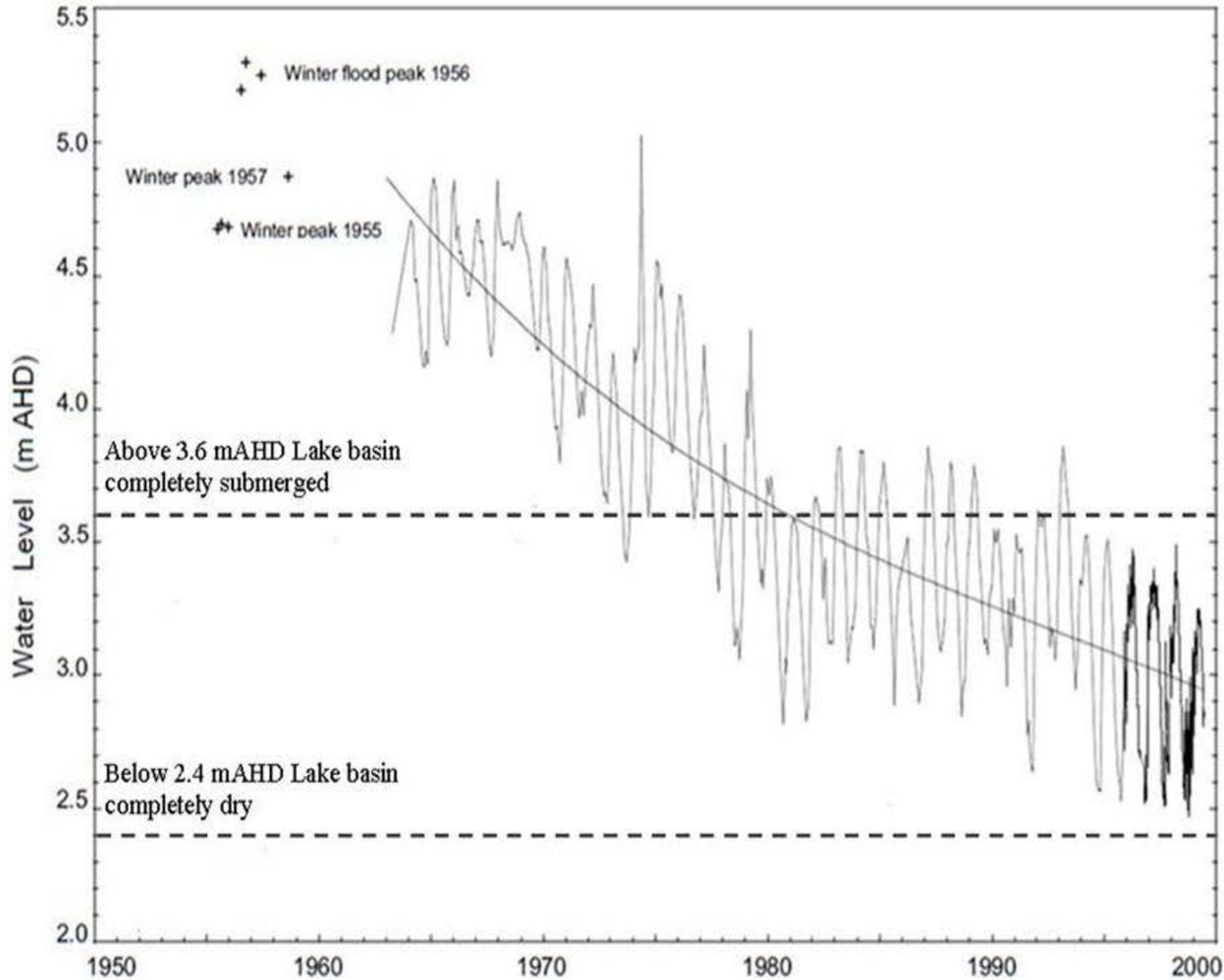
Stormwater
percolating
through
peat beds

MSc study
of nutrient
release



West Lake water level decline

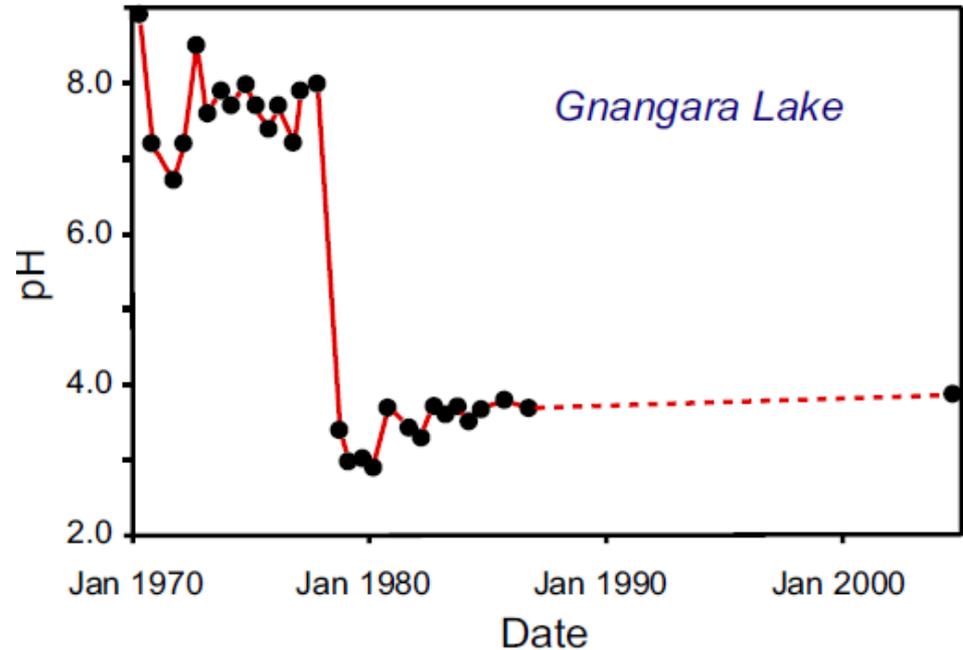
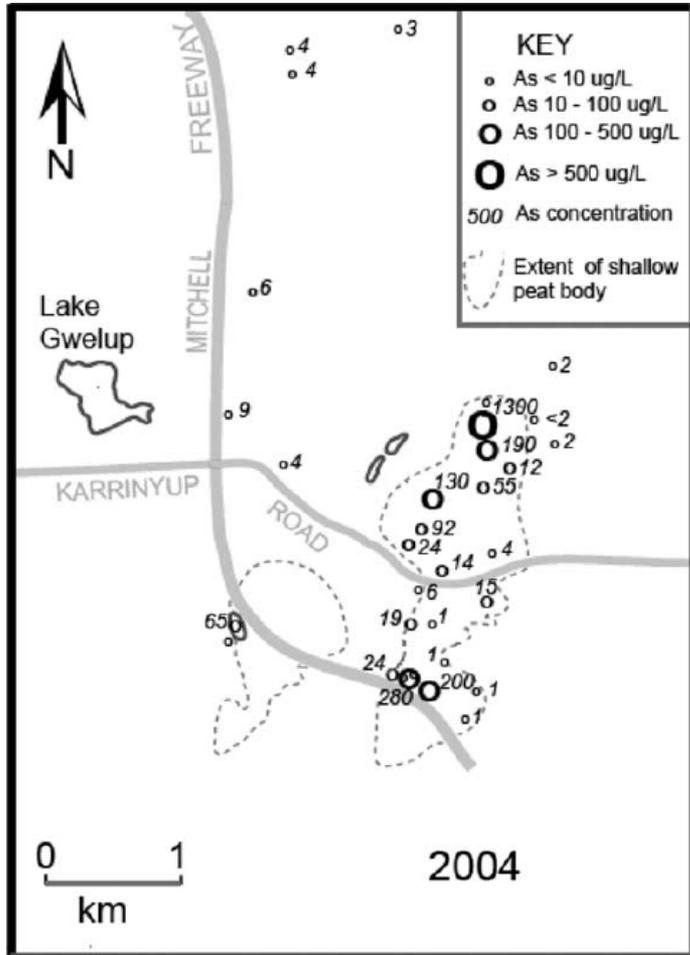
Source: John Rich (2004) Integrated Mass, Solute, Isotopic & Thermal Balances of a Coastal Wetland
Wetland Research at Perry Lakes, Western Australia 1993-1998; PhD Thesis Murdoch University



2010

Alice Drummond

Acid sulphate risk in drying wetlands



Source: Appleyard, S. and Cook T. 2009. Reassessing the management of groundwater use from sandy aquifers: acidification and base cation depletion exacerbated by drought and groundwater withdrawal on the Gnangara Mound, Western Australia. *Hydrogeology Journal*, 17: 579-588.

Arsenic, aluminium, iron release from Stirling Gardens

Source: Appleyard, S. Angeloni, J and Watkins, R (2006). Arsenic-rich groundwater in an urban area experiencing drought and increasing population density, Perth, Australia. *Applied Geochemistry* 21(1):83-97

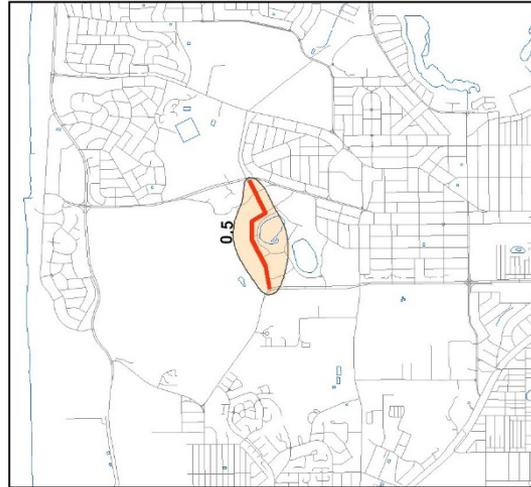


Modelled groundwater response to MAR along Perry Lakes Drive

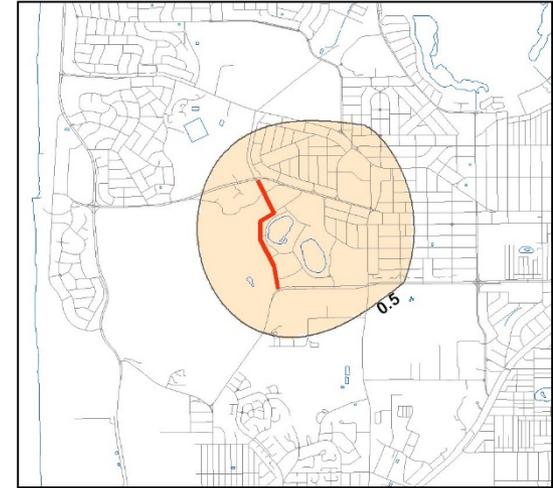
Infiltration: 1 m/d 1.3 ML/d



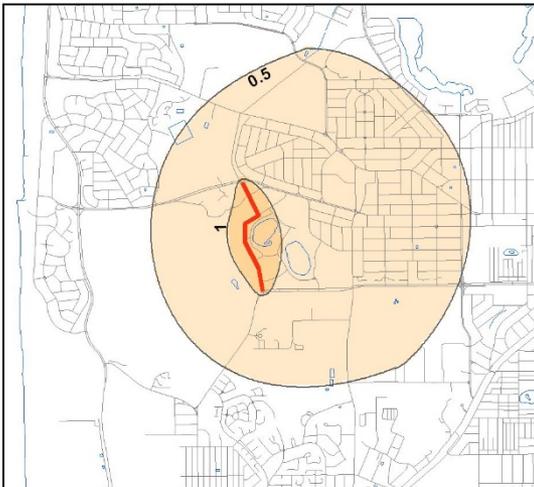
Infiltration: 2 m/d 2.7 ML/d



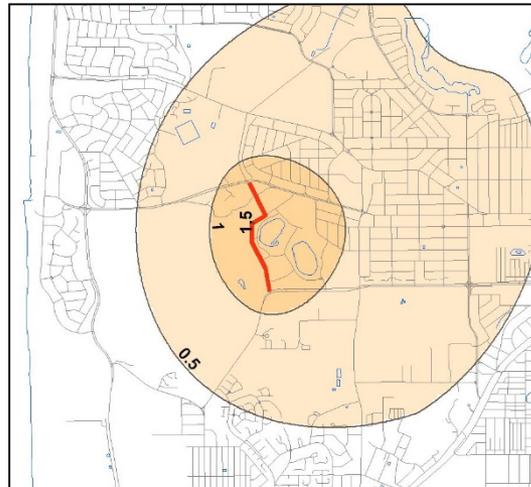
Infiltration: 3 m/d 4 ML/d



Infiltration: 4 m/d 5.3 ML/d



Infiltration: 5 m/d 6.7 ML/d



Direction of
groundwater flow
←

Source: McFarlane, D.J., Smith, A.,
Bekele, E., Simpson, J. and
Tapsuwan, S. (2009). Using treated
wastewater to save wetlands affected
by climate change and pumping.
Water Science and Technology 59(2):
213-221S

Most of the raised groundwater levels are up-gradient of the point of infiltration – ‘underground dam’ effect

Structural Gallery Design

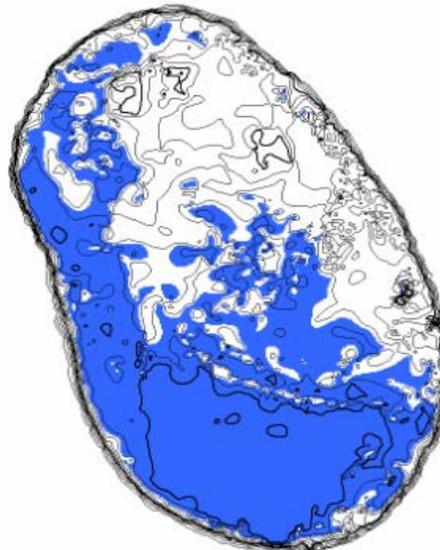
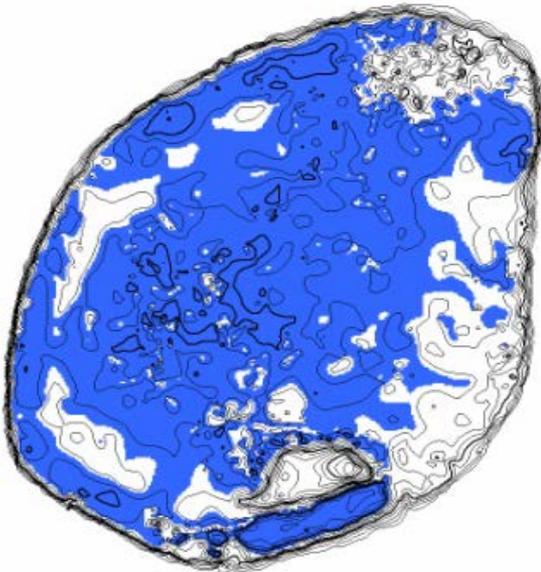
Source: Alice Drummond BEng (Hons) thesis 2010

- 'Vertical Gallery'
 - 1 m x 1 m Atlantis crates
- 'Dual – vertical'
 - two parallel rows of galleries
- 'Horizontal Gallery'
 - 52 mm x 4.5 m Flo-cells



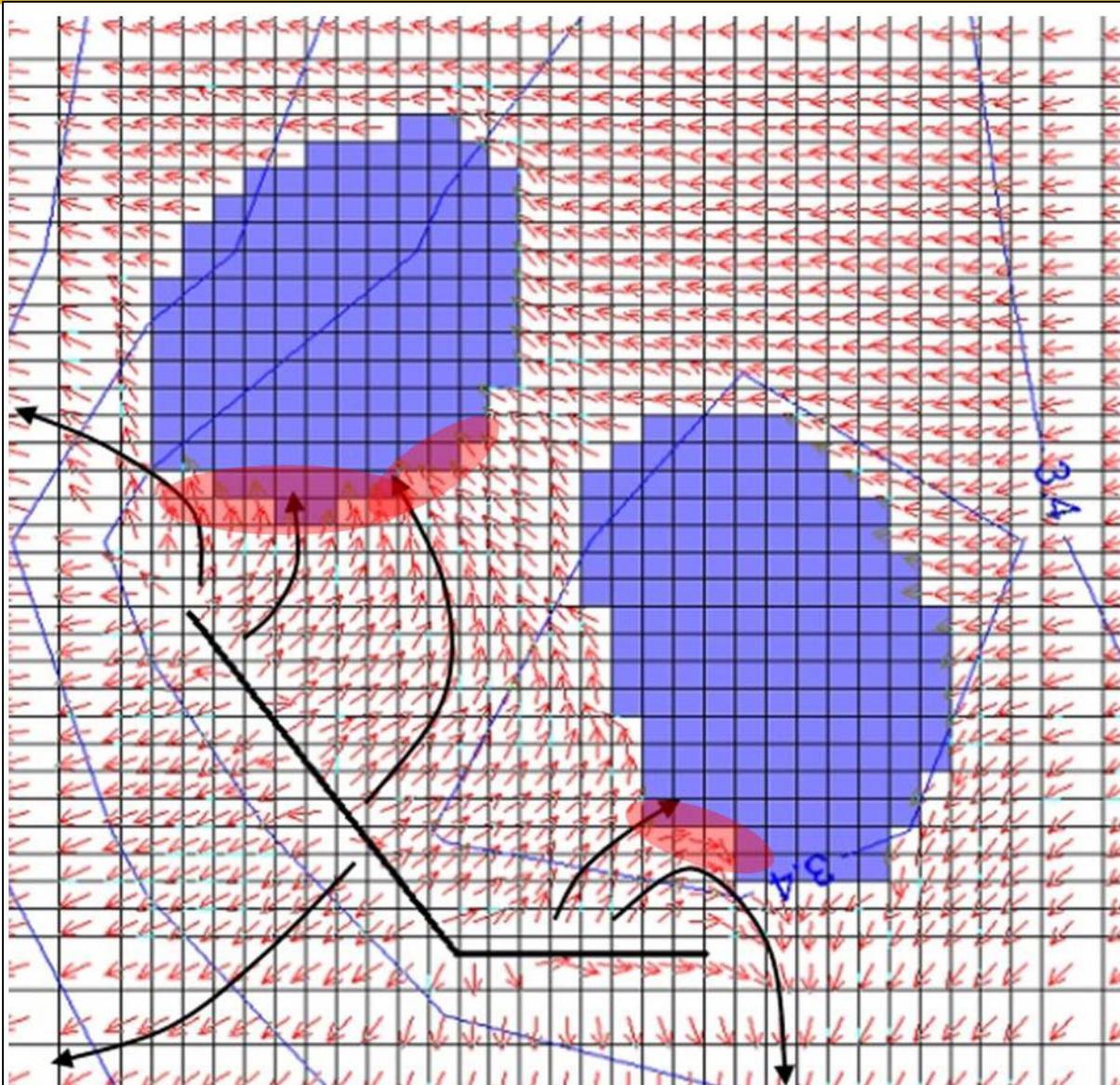
West Lake

East Lake



Groundwater modelling of gallery options at Perry Lakes

Source: Alice Drummond BEng (Hons) thesis 2010



- ≈ 80 days for infiltrated water to reach both lakes under high infiltration scenario
- Full response within 1 year
- Could be finessed to reduce risk of lake ingress and achieve desired lake levels over time

Design Option	Water Source	Gallery design	Capital cost	Operating cost	Net Present cost
1.	Amiad	Horizontal	\$1.95 mil	\$311,000	\$7.72mil
2.	Screen	Horizontal	\$3.38mil	\$208,000	\$7.25 mil
3.	Screen	Single-vertical	\$3.13 mil	\$231,000	\$7.51 mil
4.	Screen	Dual-vertical	\$3.23 mil	\$179,000	\$6.65 mil
5.	Screen	Horizontal	\$3.01 mil	\$172,000	\$6.31 mil
6.	Screen	Dual-vertical	\$2.98 mil ↓	\$162,000 ↓	\$6.10 mil ↓

Pre-treatment, gallery type and length, were simulated and costed

One of six options are shown here

Source: Alice Drummond BEng (Hons) thesis 2010





Diverting Herdsman to Floreat main drain to Perry Lakes



Costed by Water Corporation in 1990s

Rockwater (2017) costing: \$2.345M capital,
\$45K per annum operating

Source: Rockwater (2017) PERRY LAKES WATER
OPTIONS ASSESSMENT: REPORT FOR TOWN OF
CAMBRIDGE

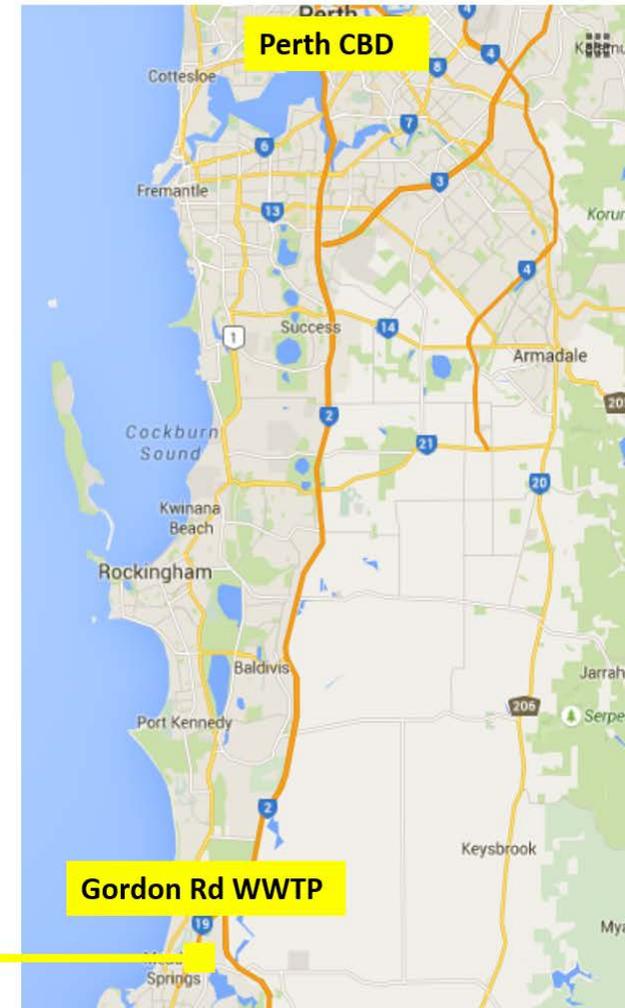
Main drain flows have fallen in recent years
(in the 1990s it was ca. 10 GL/y)

Could be diverted into Wembley Golf
Course for use in northern part of Town

Rockwater (2017) also costed MAR options
using Subiaco WWTP water:

- Galleries \$1.36M capital, \$125K operating
- Interdunal swale (Camel Lake) \$390K capital, \$125K operating

Gordon Road WWTP

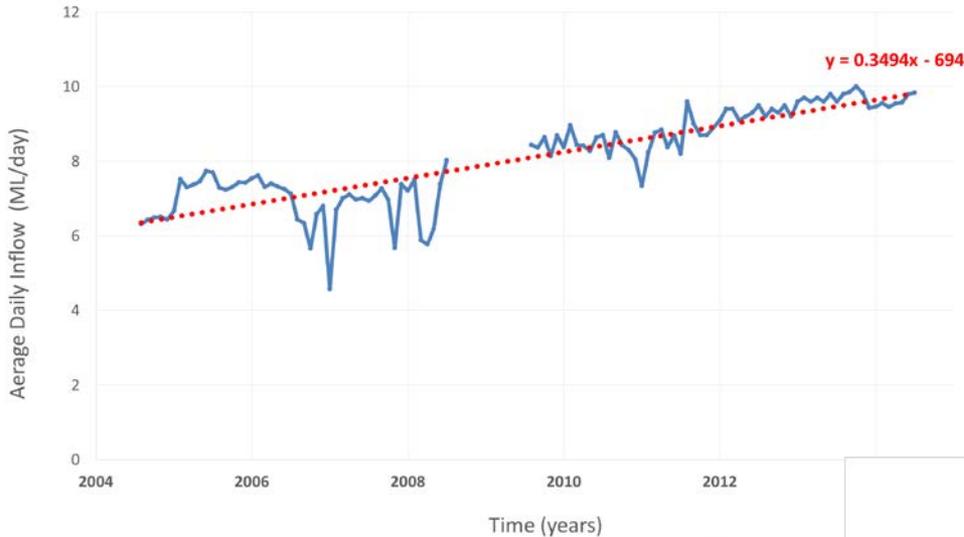


Gordon Road WWTP inflow and groundwater levels

Source: Hydrogeological Impact Assessment of Infiltrated Treated Wastewater at the Gordon Road Wastewater Treatment Plant. MSc Hydrogeology Thesis UWA
Rob Pavlov 2015

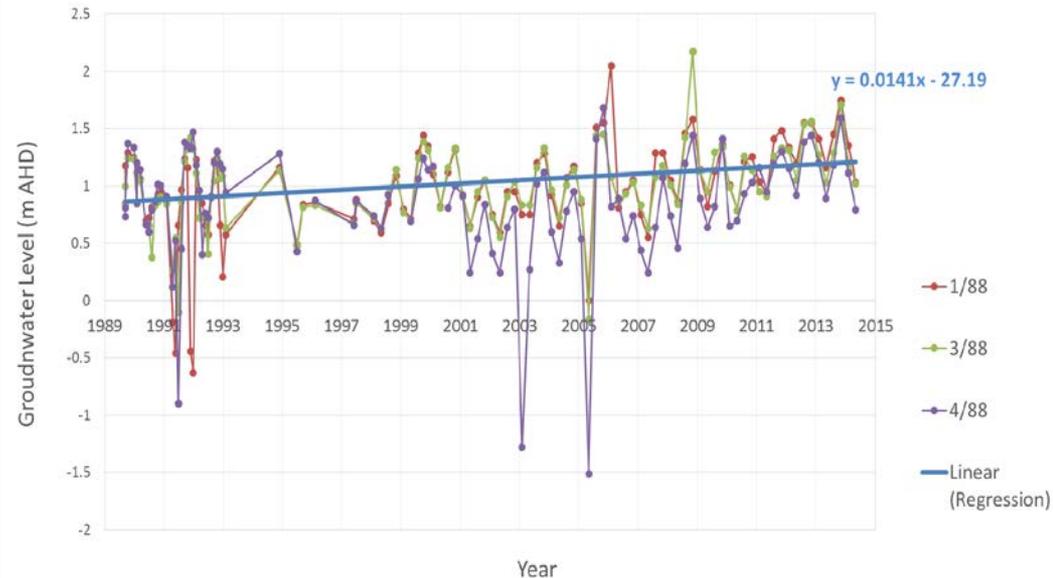


Effluent Inflow and Outflow

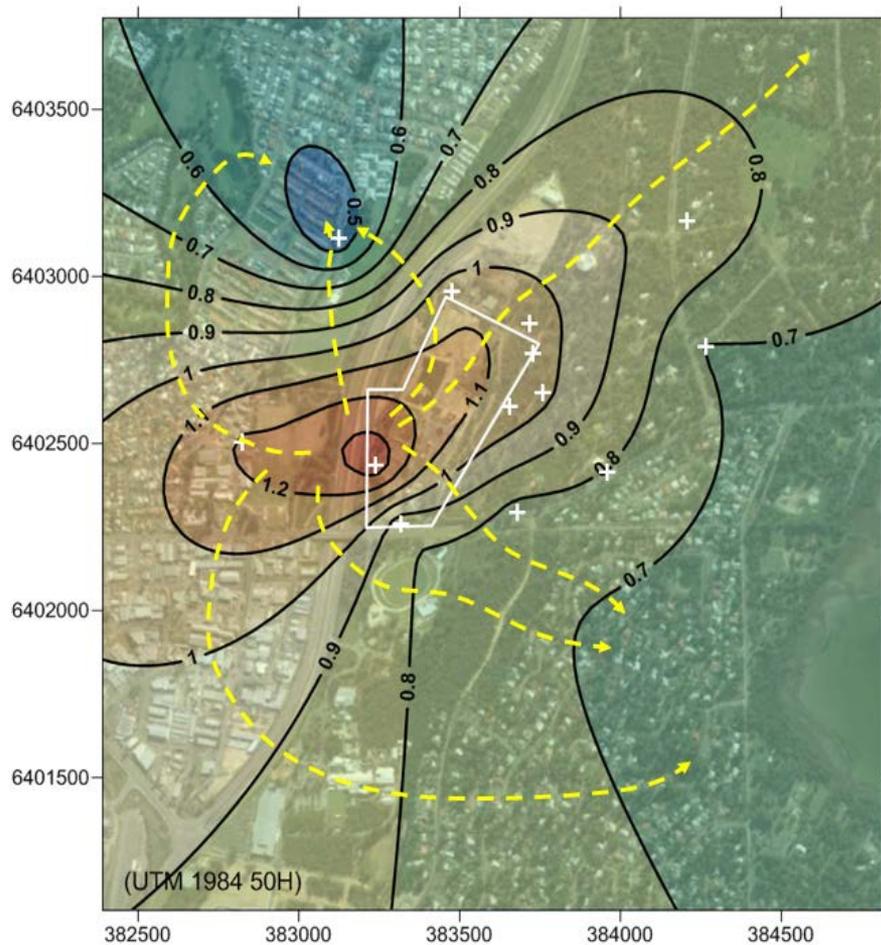


Groundwater levels have risen along with discharge despite a drying climate and increased demand for irrigation from nearby areas

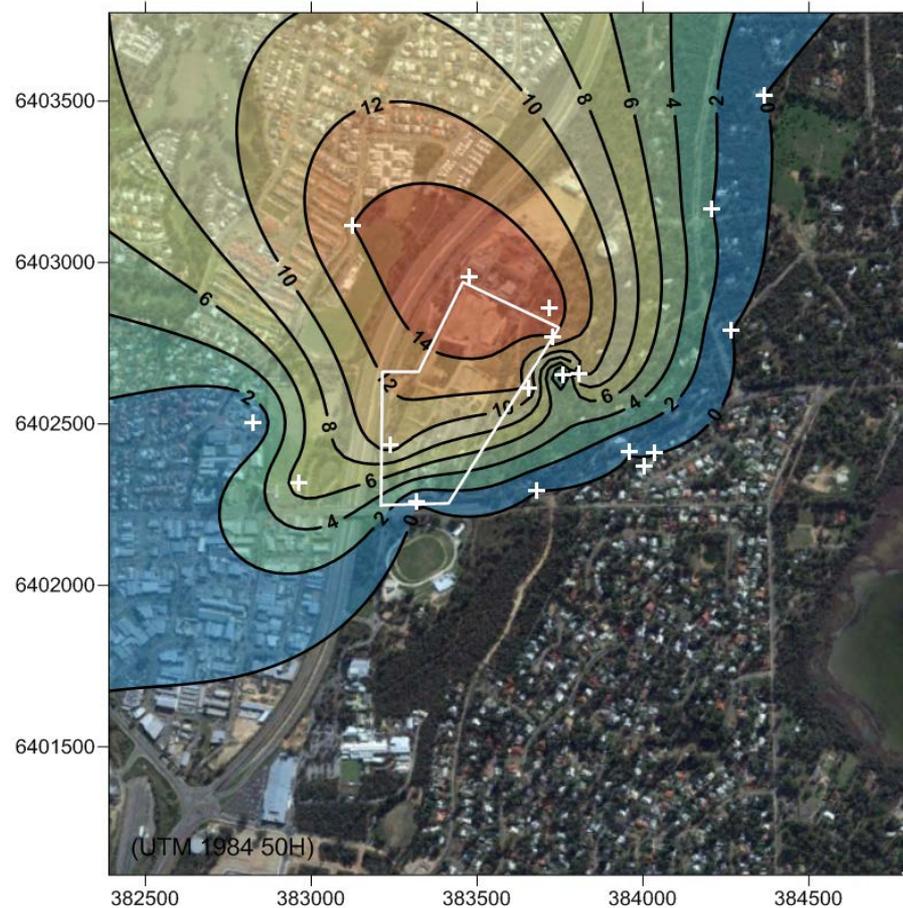
Historical Groundwater Levels



Infiltration from basins at the Gordon Road WWTP



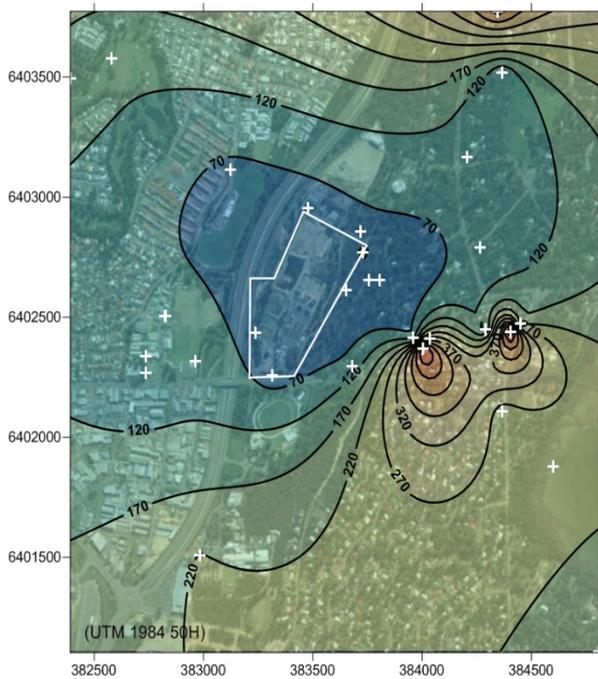
Groundwater levels (m AHD)



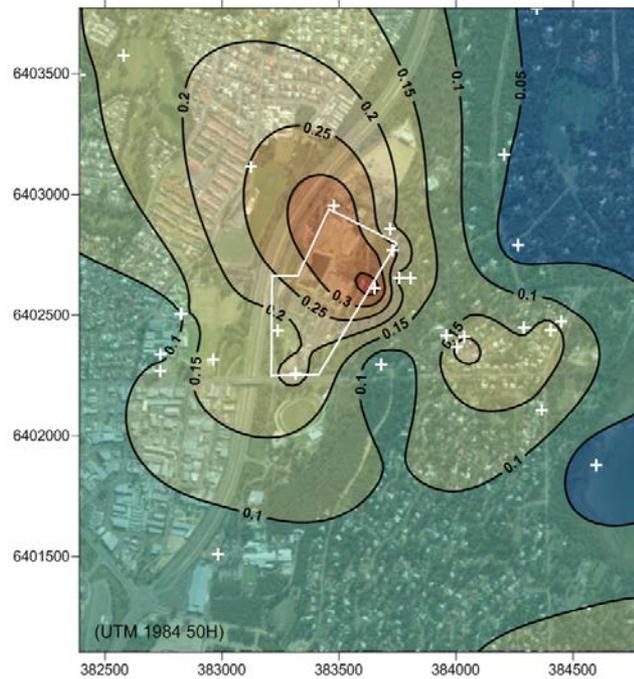
Sucralose ($\mu\text{g/L}$)

Source: Hydrogeological Impact Assessment of Infiltrated Treated Wastewater at the Gordon Road Wastewater Treatment Plant. MSc Hydrogeology Thesis UWA Rob Pavlov 2015

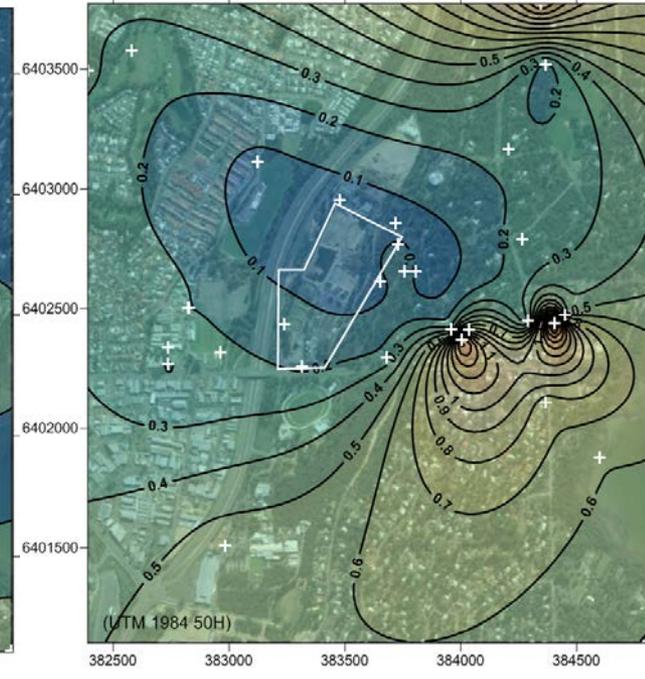
Chloride, Fluoride and Bromide in groundwater



Chloride ($\mu\text{g/L}$)



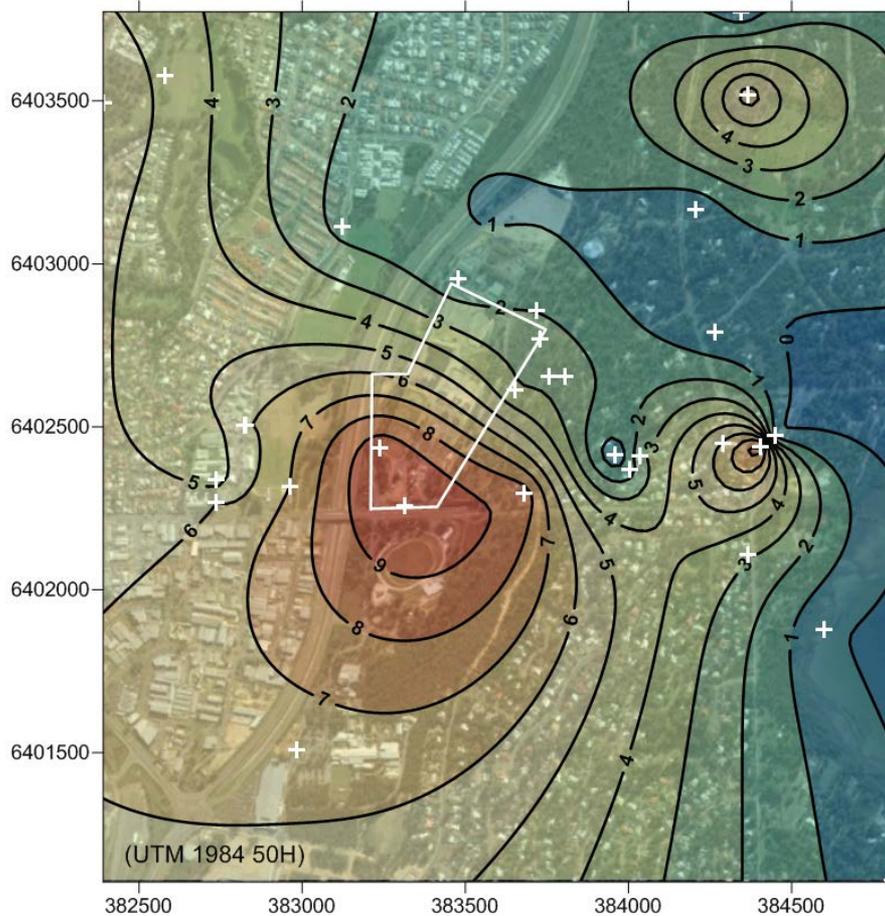
Fluoride mg/L



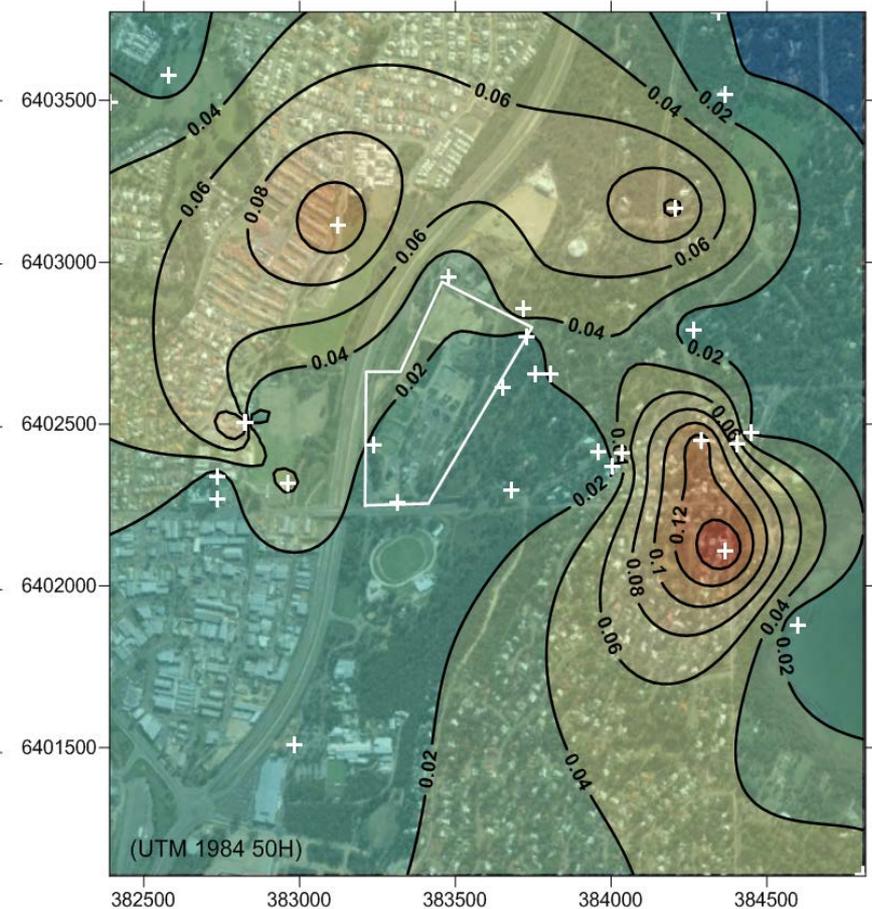
Bromide mg/L

Source: Hydrogeological Impact Assessment of Infiltrated Treated Wastewater at the Gordon Road Wastewater Treatment Plant. MSc Hydrogeology Thesis UWA Rob Pavlov 2015

Nutrients in groundwater around the Gordon Road WWTP

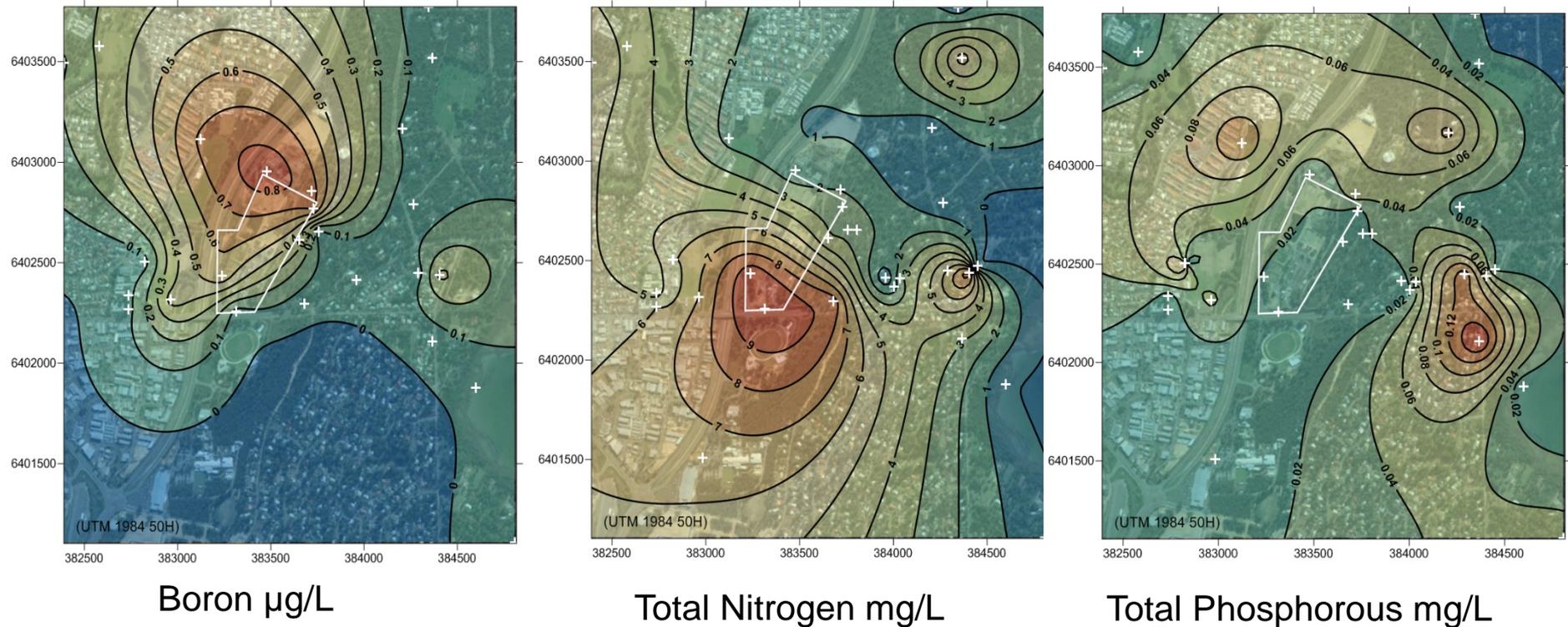


Total Nitrogen mg/L



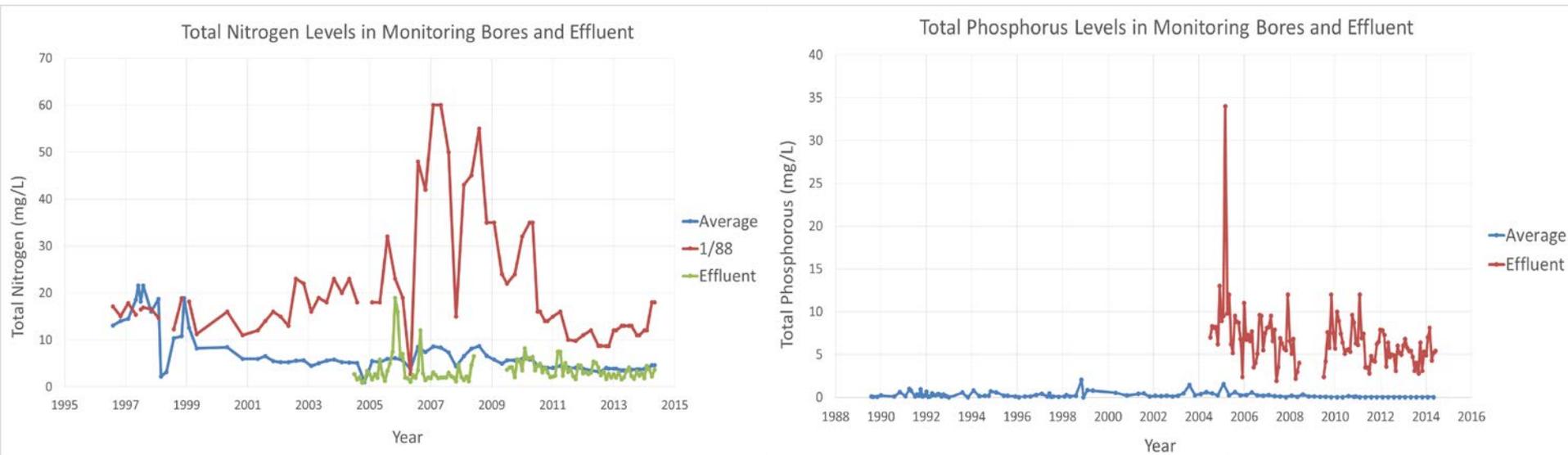
Total Phosphorous mg/L

Boron, Total Nitrogen and Total Phosphorus in groundwater



- Boron would be toxic if plants used treated wastewater for very long periods
- Nitrogen reflects historical drying of biosolids, not TWW additions
- TWW Phosphorus is removed in Tamala Limestone aquifer but higher under fertilised turf

Trends in Total N and P in wastewater and groundwater



Decreasing nutrient levels in groundwater and effluent.

Source: Hydrogeological Impact Assessment of Infiltrated Treated Wastewater at the Gordon Road Wastewater Treatment Plant. MSc Hydrogeology Thesis UWA Rob Pavlov 2015

Conclusions 1



- **Open-pit infiltration** using treated wastewater disposal at 33 WWTPs shows that water of secondary treatment quality can be infiltrated over long periods with modest maintenance costs. Similar longevity occurs in stormwater basins
- **Covered infiltration galleries** have advantages in that they are hidden, don't emit odours and allow public access. By excluding light they also reduce algal and biofilm growth, a major cause of clogging. Tree and grass roots also need control
- They are however more expensive to install and maintain.
- Experience with septic tanks drains in pre-sewered areas is another guide to performance, with these using much lower quality water. Bassendean Sands perform much worse than Spearwood Sands
- Soils and aquifers can be too oxygenated to cause denitrification unless a carbon source is added.
- Dissolved organic carbon, phosphorus and pathogens can be greatly reduced in MAR into Spearwood Sands and Tamala Limestone

Conclusions 2

- MAR can slow groundwater discharge to river and ocean outlets, increasing the yield of aquifers and could rejuvenate throughflow wetlands and GDEs
- Risks caused by higher nitrogen can be alleviated by intercepting and using MAR water, and possibly by adding a carbon source if nitrified and anoxic
- The 'do nothing' option is not without risks:
 - Acid sulphate soil formation, release of arsenic and aluminium
 - Peat oxidises and release its nutrients
 - Loss of phreatophytes
 - Reduced irrigation, loss of amenity and recreational options (public health), environment values and heat island impacts
- SW WA has been late to adopt MAR because we have be spoiled with easy access to shallow groundwater and a desire not to contaminate such a valuable resource
- We can use our long experience with stormwater and wastewater disposal to catch up with states like South Australia who had to adopt MAR because their needs were much greater

Infiltration and reuse at Halls Head WWTP

Source: Simon Toze, CSIRO



Results are very similar to the Floreat Infiltration Galleries ←

Thank you

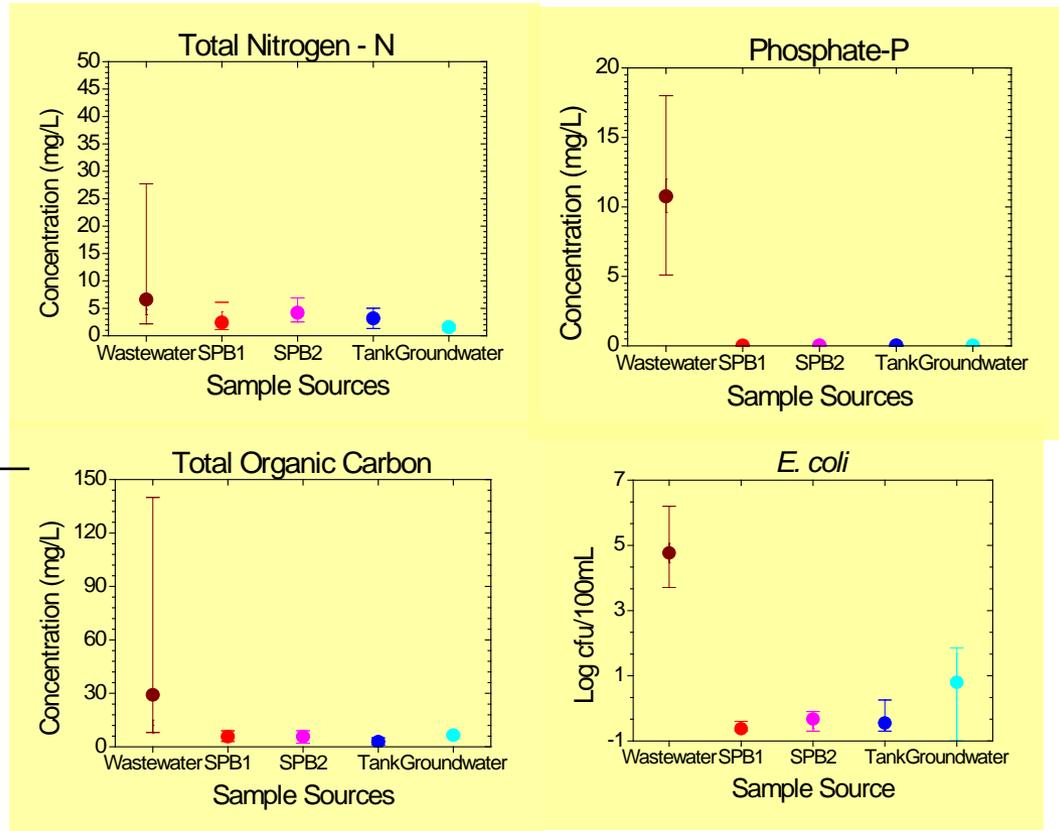
Dr Don McFarlane

Adjunct Professor

School of Agriculture and Environment
University of Western Australia

Mobile: 0407 476 026

Email: don.mcfarlane@outlook.au



WGA

WALLBRIDGE GILBERT
AZTEC

Moving to an Operational Scheme - Issues and Management

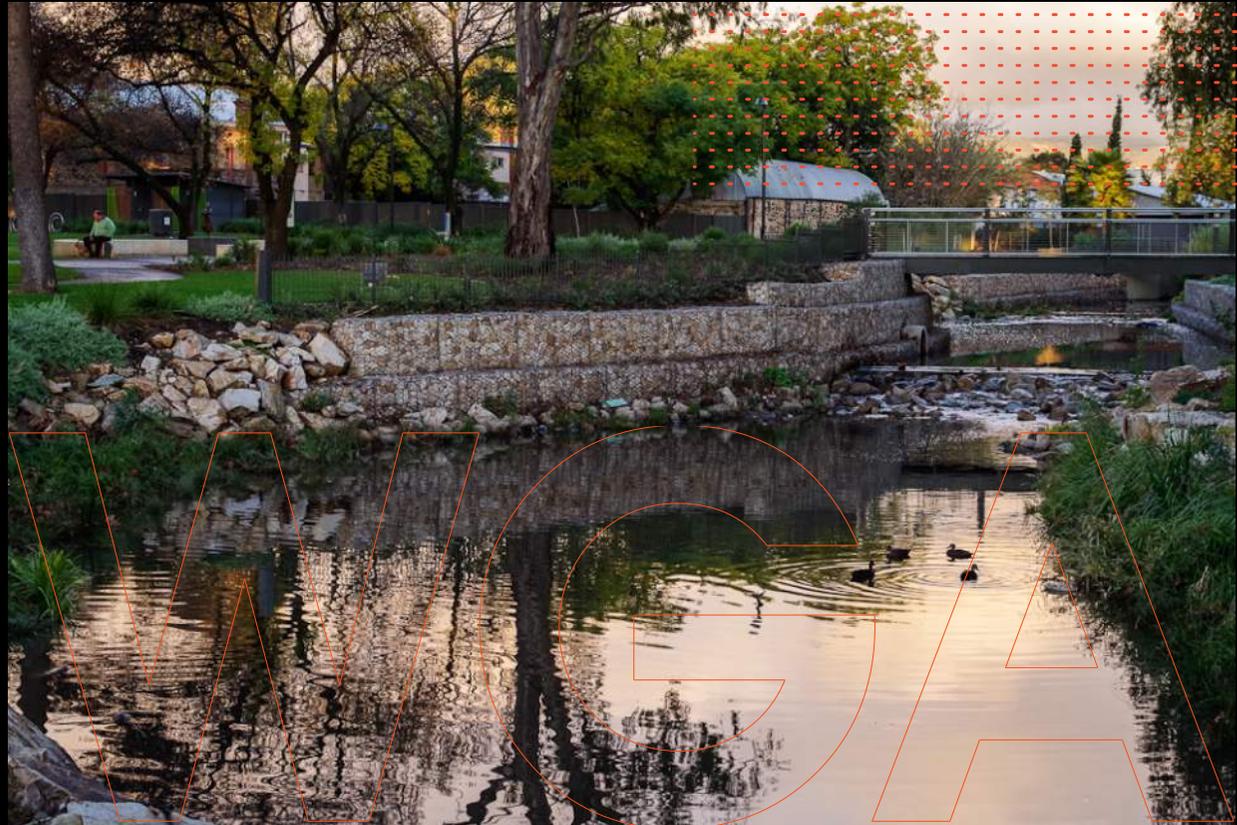
October 2017

RUSSELL MARTIN
Principal Hydrogeologist

rmartin@wga.com.au
Ph +61 438 110 700

www.wga.com.au

45 minutes



Outline

1. Issues for MAR Systems
2. Clogging
3. Treatment Methods
4. Lessons learned



Issues for injection bores

- Injection bores
 - Clogging
 - Bore construction
 - Acid production
 - Aquifer heterogeneity
 - Mineralogy
 - Maintenance and monitoring
 - Hydraulic impacts
 - Fault activation



Matters to consider in water banking

- Aquifer heterogeneity
- Existing users hydraulic impacts
- Aquifer thickness
- Hydraulic characteristics
- Transmissivity, leakance, porosity, potential for internal flow
- Dispersivity
- Potential for losses due to density stratification and/or lateral movement



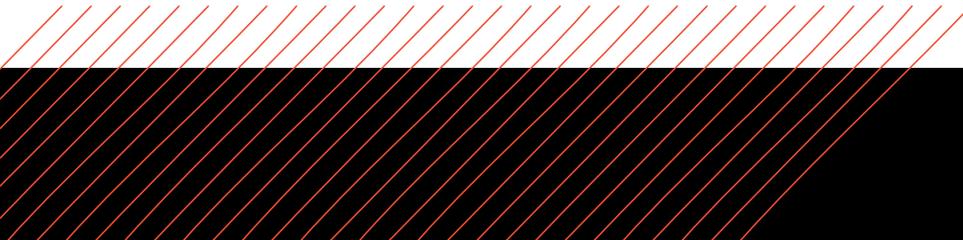
Environmental considerations

- Chlorine and Trihalomethane
- Endocrine disruptors (applies only to Recycled Water)
- Nutrients
- Groundwater Dependent Ecosystems (GDEs) e.g. Stygofauna
- Fate of Pathogens



Endocrine disruptors - wastewater

- Pharmaceutical or endocrine disrupting compounds (EDCs) are often raised as a potential risk associated with reuse of treated wastewater for ASR.
 - Medical research has shown that between 90 to 95% of the prescribed pharmaceutical products are taken up in the body. Only a very small amount is passed.
- Studies (Ying et. al., 2004) for two estrogen compounds in aquifer materials showed 50% biodegradation within approximately 2 days under aerobic conditions but 2 -3 time slower under anaerobic conditions for one of the estrogen compounds.
- The second compound ethynylestradiol (EE2) was found to be persistent under both aerobic and anaerobic conditions.
- Further research is required into the natural attenuation of endocrine disrupters in the environment .
- Studies (e.g. Redding et. al. 2006) have shown that following micro filtration and/or use of activated carbon membrane filtration (typical in water treatment) endocrine disruptors are well below the current laboratory capabilities of detection (less than ppb detection).

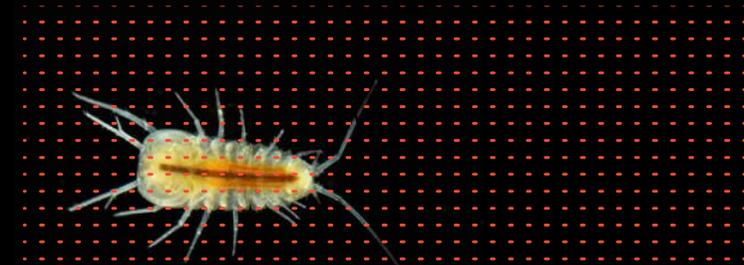


Nutrient reduction during MAR

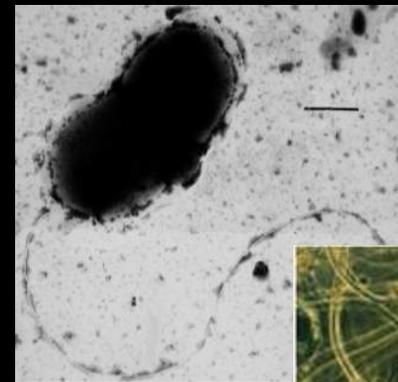
- TOC reduction generally occurs particularly at ASR wells with higher recharge TOC concentrations
- Total N reduction up to about 90%
 - Oxidation of ammonia to nitrate
 - Denitrification if/when ORP declines
 - “Annamox” process under certain conditions (bacteriological reduction of nitrogen) and bacteria responsible identified as recently as 1999.
- Phosphorus reduction up to about 90%
 - Initial geochemical adsorption process in carbonates
 - Delayed microbial process after several weeks/months

Groundwater Dependent Ecosystems (GDEs)

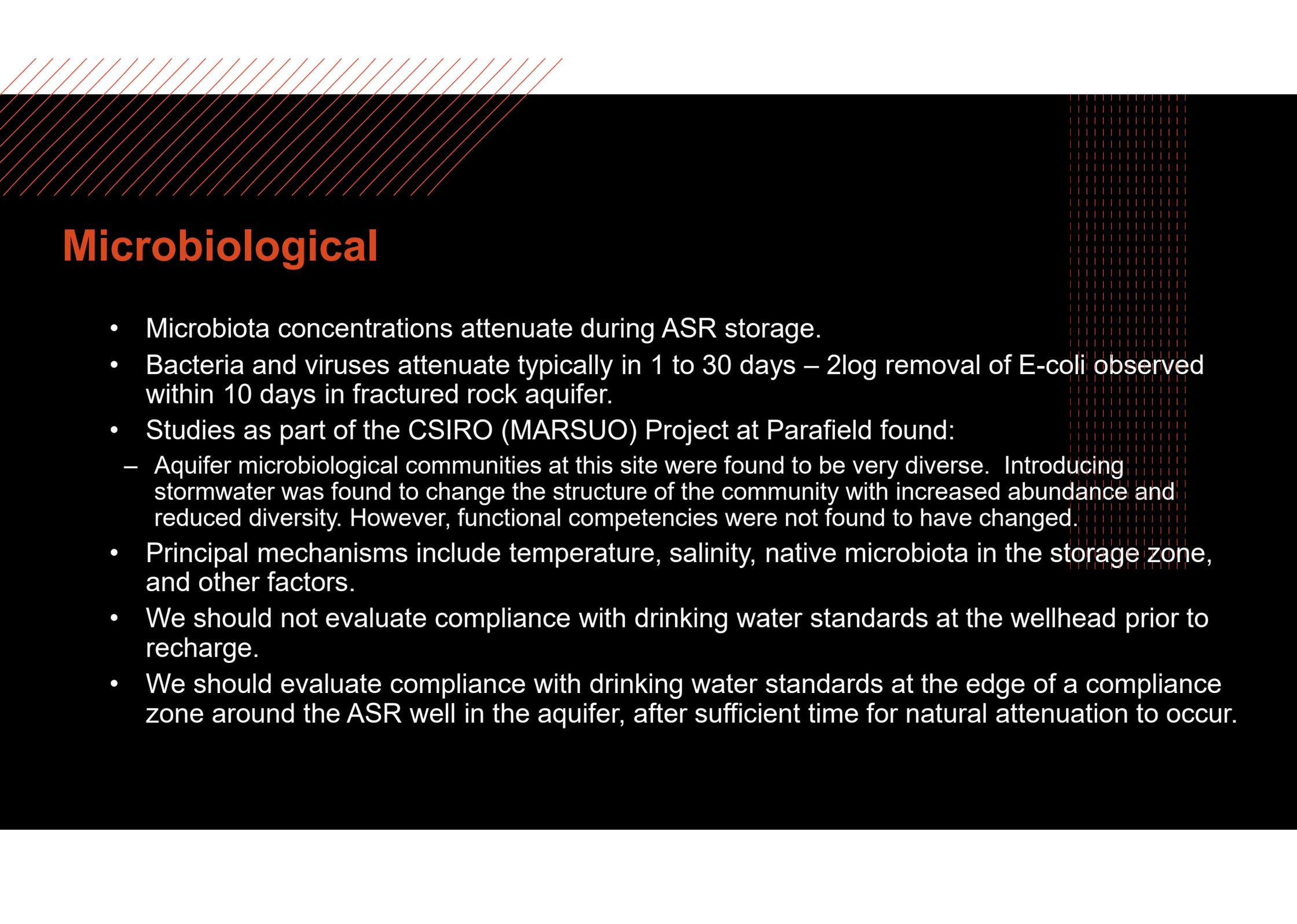
- All aquifer systems have healthy microbiological communities.
- These communities are found to be extensive and assist in attenuation and improvement of the quality of injected water during storage.
- They also assist in the removal of pathogens (refer various papers Toze et. al. 2004 through 2012).
- Researchers in the US (e.g. Liesel, 2009, Upper Floridian aquifers) have identified that introduction of a new water type does not adversely impact these organisms which quickly adapt to the altered conditions.
- Microbes are being increasingly used as a method to clean up contaminated groundwater systems.



Sulphate Reducing Bacteria



Iron Bacteria



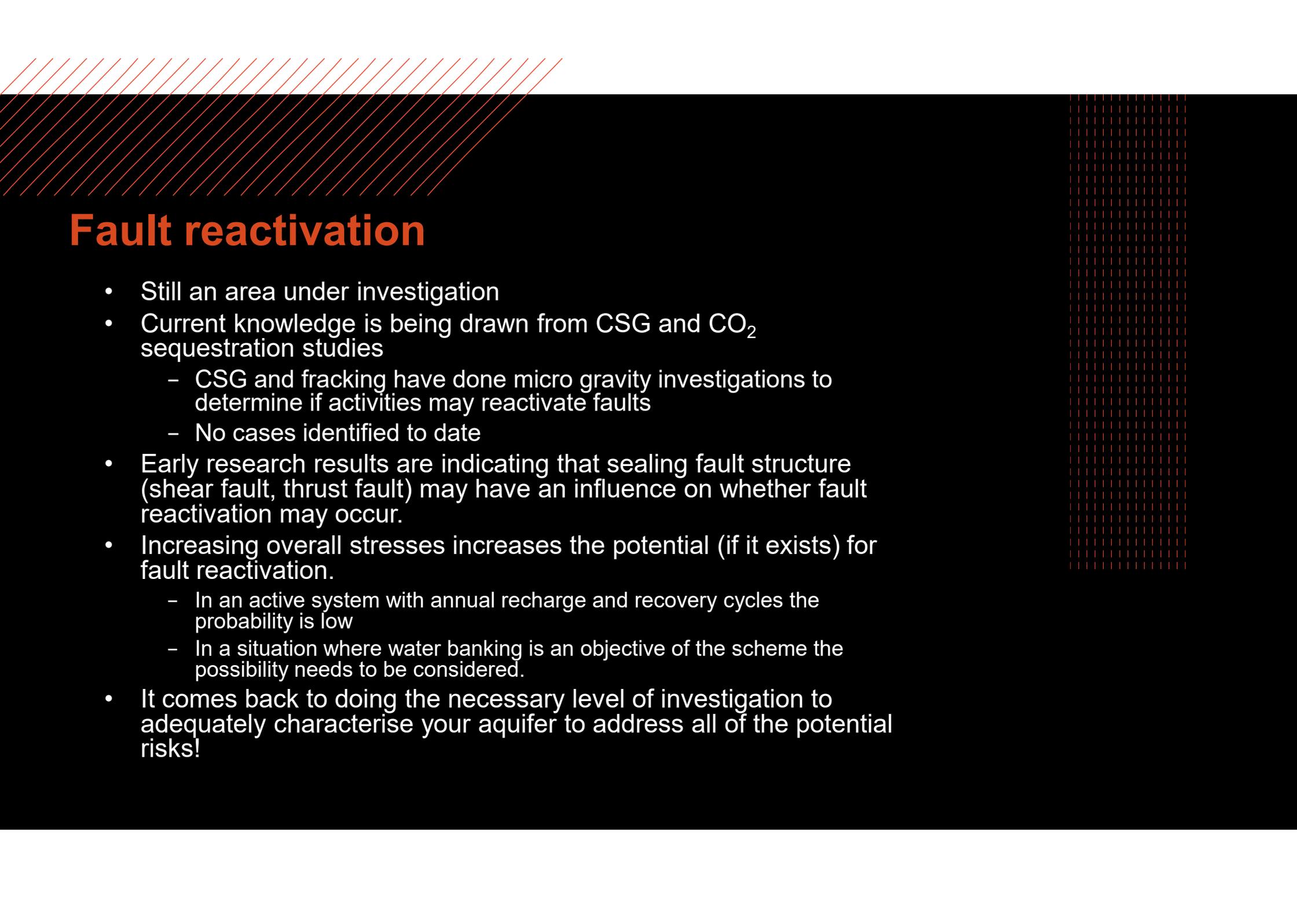
Microbiological

- Microbiota concentrations attenuate during ASR storage.
- Bacteria and viruses attenuate typically in 1 to 30 days – 2log removal of E-coli observed within 10 days in fractured rock aquifer.
- Studies as part of the CSIRO (MARSUO) Project at Parafield found:
 - Aquifer microbiological communities at this site were found to be very diverse. Introducing stormwater was found to change the structure of the community with increased abundance and reduced diversity. However, functional competencies were not found to have changed.
- Principal mechanisms include temperature, salinity, native microbiota in the storage zone, and other factors.
- We should not evaluate compliance with drinking water standards at the wellhead prior to recharge.
- We should evaluate compliance with drinking water standards at the edge of a compliance zone around the ASR well in the aquifer, after sufficient time for natural attenuation to occur.

Microbiological control

- Pathogens
 - Viruses and bacteria can be controlled by chlorination.
 - Protozoa to meet 3rd pipe requirements or drinking water quality require 1.8 log removal which cannot be achieved by chlorination alone.
 - Additional treatment required e.g. ozonation ,UV etc
 - Other combination treatments could also be considered, e.g. aquifer treatment.



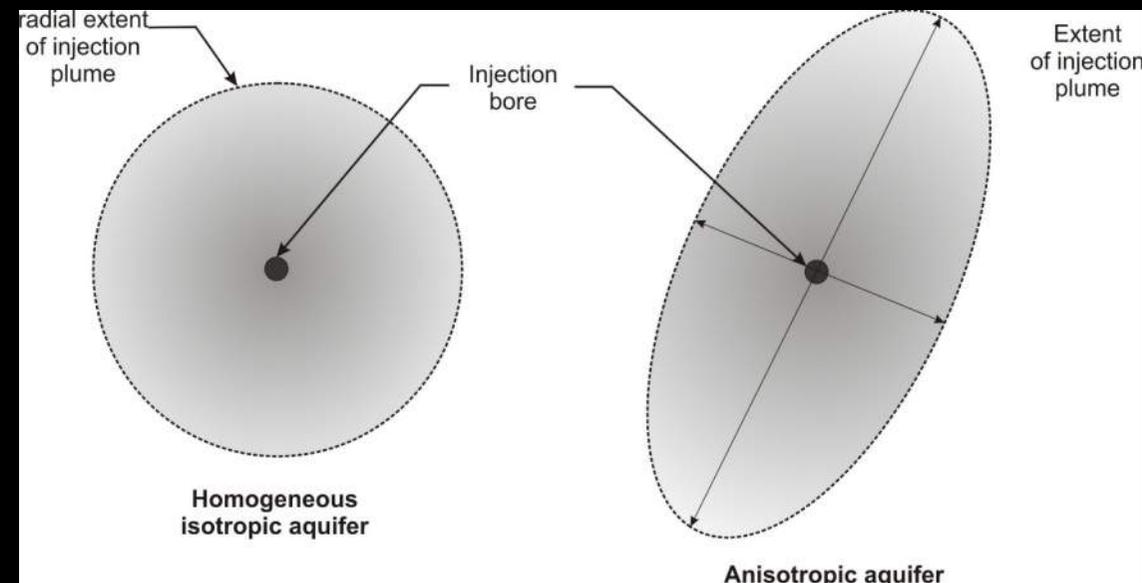


Fault reactivation

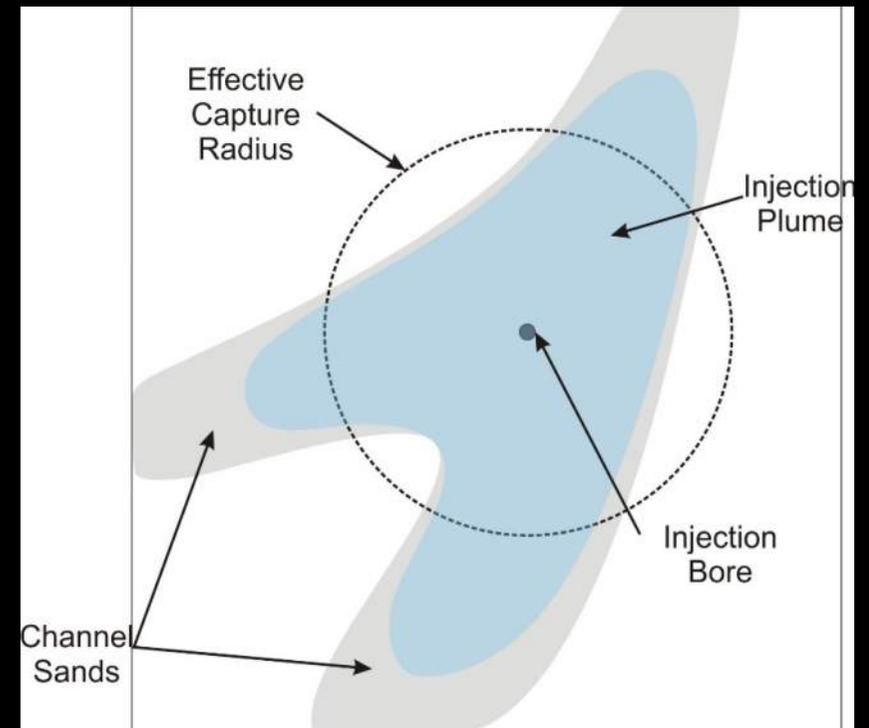
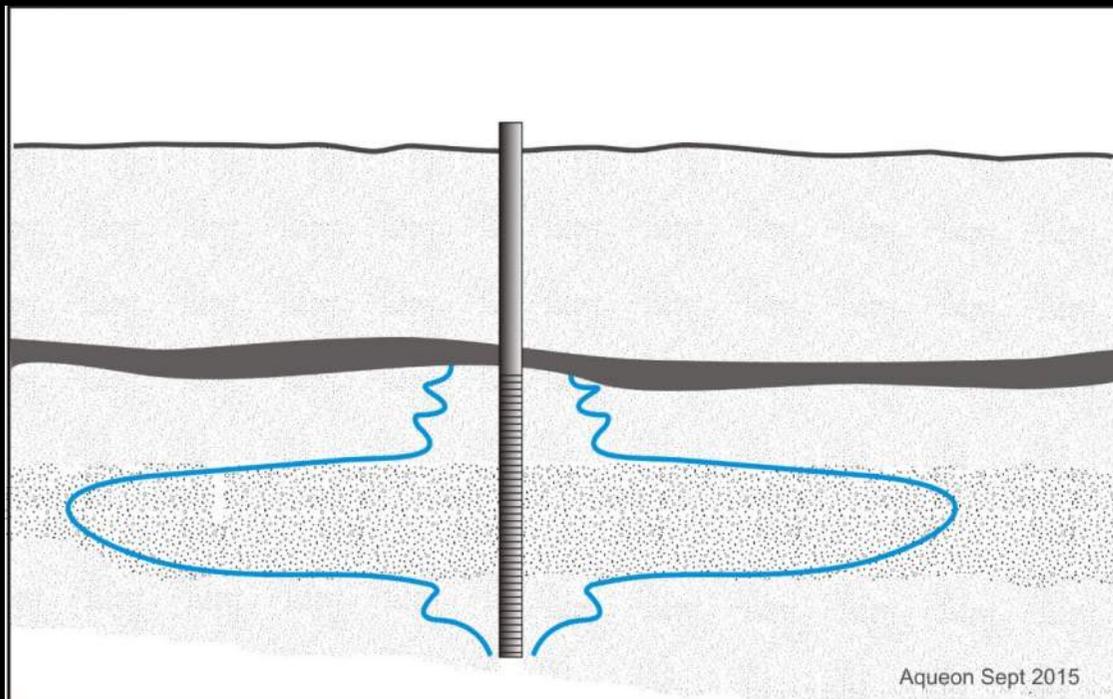
- Still an area under investigation
- Current knowledge is being drawn from CSG and CO₂ sequestration studies
 - CSG and fracking have done micro gravity investigations to determine if activities may reactivate faults
 - No cases identified to date
- Early research results are indicating that sealing fault structure (shear fault, thrust fault) may have an influence on whether fault reactivation may occur.
- Increasing overall stresses increases the potential (if it exists) for fault reactivation.
 - In an active system with annual recharge and recovery cycles the probability is low
 - In a situation where water banking is an objective of the scheme the possibility needs to be considered.
- It comes back to doing the necessary level of investigation to adequately characterise your aquifer to address all of the potential risks!

Aquifer heterogeneity

- Low recovery efficiency
 - Excessive salinity
- Variable transmissivity across the production bore field
 - Preferential flow
 - Different injection rates for different bores
- Remediation
 - Remediation approaches and success will be different for each bore
- Fate and behaviour of aquifer microbiology and any introduced pathogens will be different between bores.

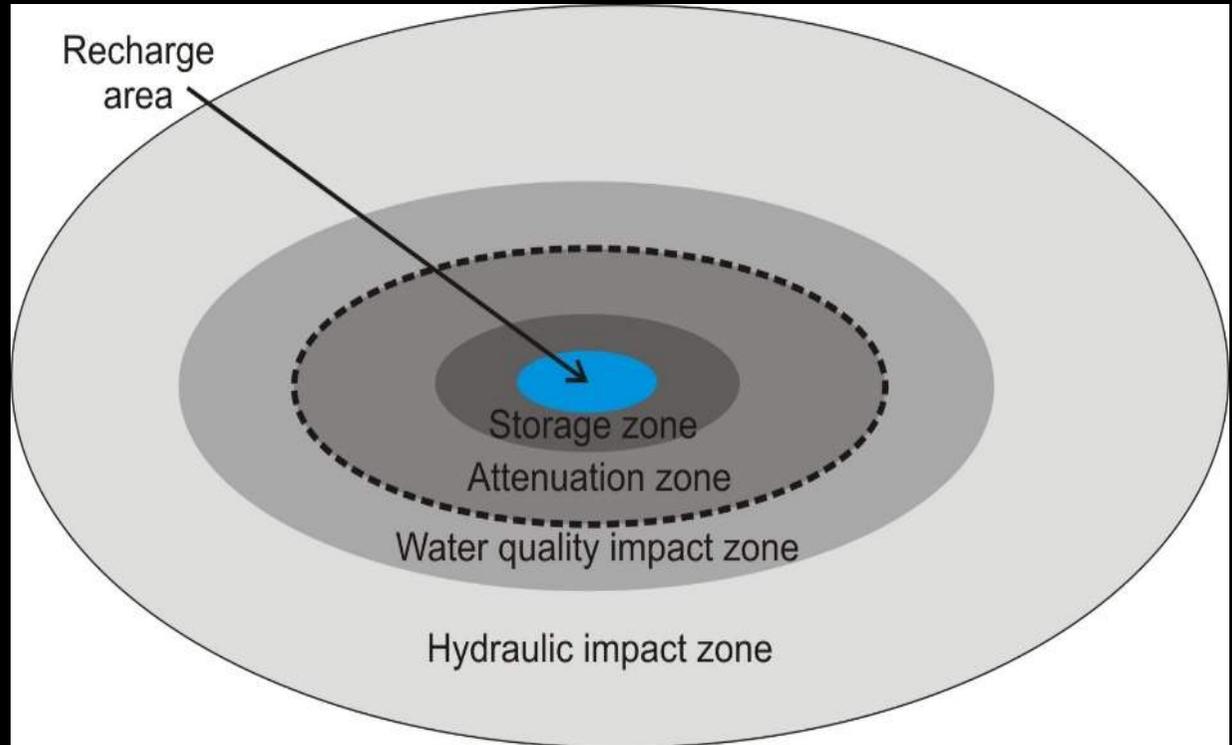


Aquifer heterogeneity (cont'd)



Hydraulic impacts

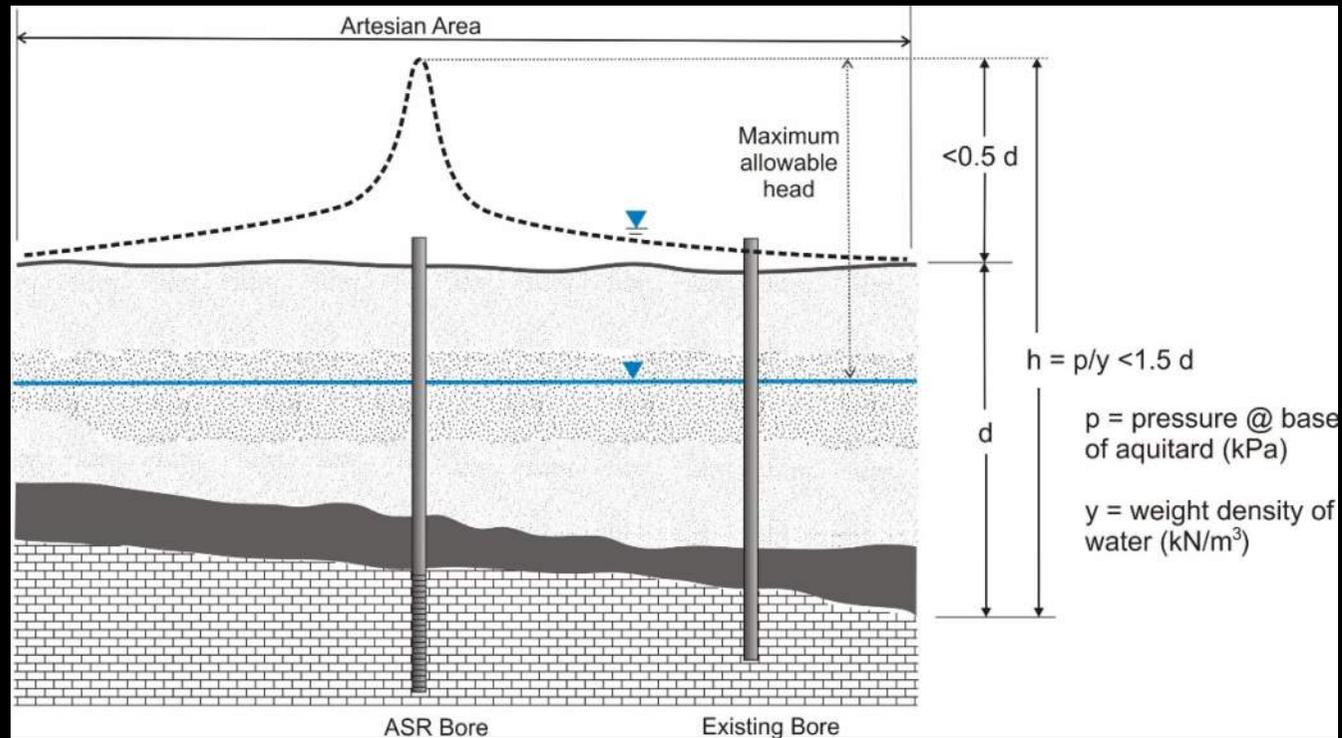
- Zones of influence critical in confined aquifers to assess potential impacts on existing third party users.



Source: Dillon et. al. NWC waterlines project No. 13

Maximum allowable injection pressure

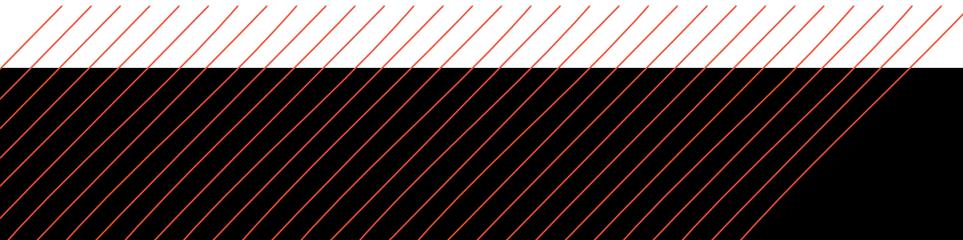
- Constrain operational head so as not to over pressurise the aquifer.
- Formula is conservative as it neglects water in shallow aquifers.



Managing hydraulic impacts – confined aquifer

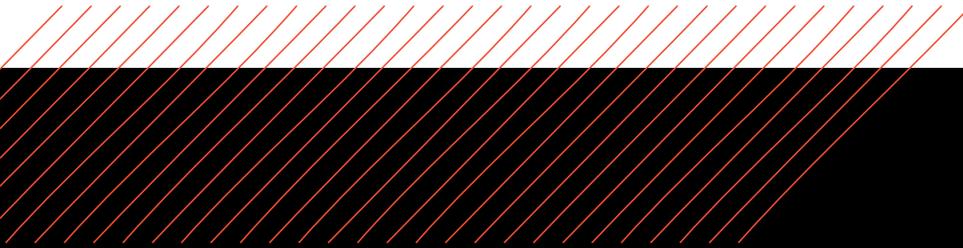
- Pump selection to constraining injection pressure
- Estimate of the region likely to be made artesian and check for wells and determine ability to cap
- For semi-confined aquifers calculate loss of water and its constituents to other aquifers and determine likely changes in head
- Restrict volume and rate of recharge and recovery to acceptable levels and for acceptable periods
- In unconsolidated aquifers assess possibility of permanent deformation (subsidence)





Managing hydraulic impacts – unconfined aquifer

- Recharge of unconfined aquifers increases storage and may protect groundwater-dependent ecosystems in stressed aquifers. However, if the water table is raised too high, recharge of unconfined aquifers may also have adverse impacts.
- Examples include:
 - waterlogging
 - flooding of basements, below-ground cable ducts and depressions
 - reduced traffic access, potholes and increased road maintenance costs
 - effects of anoxia on vegetation
 - increased groundwater ingress to sewers
 - increased differential heave effects on footings in expansive clay soils, causing structural damage to buildings
 - possible mobilisation of pollutants from nearby contaminated sites



Managing hydraulic impacts - unconfined aquifer

- Determine water table rise and hence potential impacts on structures (e.g. basements and footing movement for swelling soils), potential for waterlogging, change in ingress to sewers and to streams and impacts on ecosystems.
- Install overflow diversion to prevent excessive recharge head.
- Prevent use of pumps for injection.
- Avoid selecting infiltration sites that are:
 - on sloping land
 - underlain by shallow water tables or impervious layers
 - adjacent to surface depressions or groundwater-dependent ecosystems
- Restrict volume and rate of recharge to periods appropriate to the local conditions
- Increase drying time in recharge basins or infiltration galleries between infiltration events, to allow groundwater mound to subside.
- Restrict the rate of initial release for recharge releases from dams into rivers, so as not to cause a drowning hazard or excessive scour of the stream bed.



Clogging

- Why is clogging important?
 - Clogging causes impaired injectivity restricting the volume of water that can infiltrate or be injected into the target aquifer.
 - Severe clogging may lead to infiltration basins or injection bores being replaced.
 - It is the biggest risk to the successful and sustainable operation of any MAR scheme.
 - Unfortunately, it is often an excuse used by inexperienced practitioners in this specialised field for why an aquifer is not suitable for MAR.

CLOGGING WILL HAPPEN!

CLOGGING CAN BE MANAGED!

- Mitigate, either through engineering design or through operational management practices
- Note that remediation methods to address clogging are very site specific. What works in one hydrogeological setting may not always be successful in another location.

Clogging types

- 1. Physical Clogging*
- 2. Chemical Clogging*
- 3. Mechanical Clogging*
- 4. Biological Clogging*



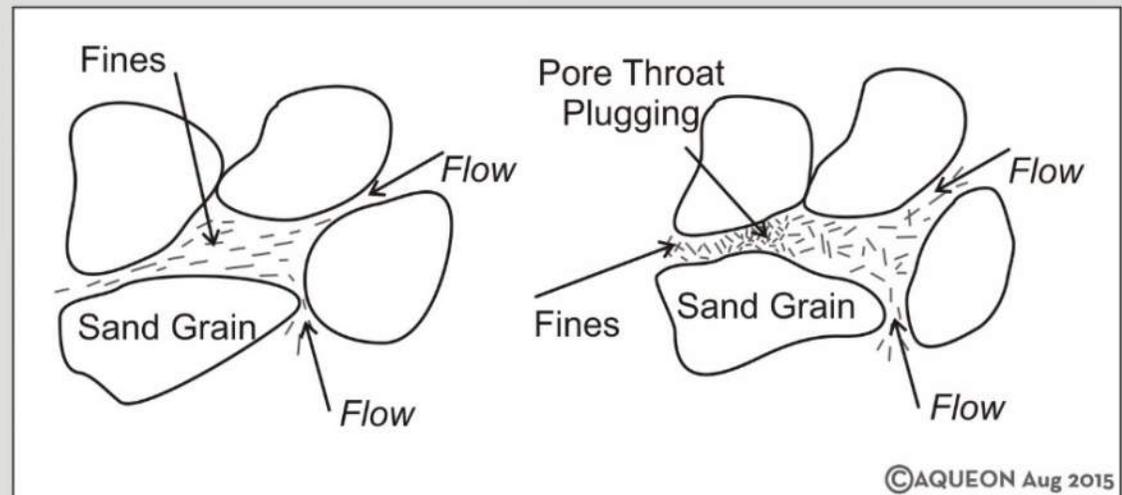
Clogging process

Clogging Types	Clogging Processes
Physical	<ul style="list-style-type: none">• Accumulation / Injection of organic and inorganic suspended solids.• Velocity induced damage e.g. migration of interstitial fines such as illite or smectite.• Clay swelling (e.g. montmorillonite).• Clay deflocculation.• Invasion of drilling fluids (emulsifiers) deep into the formation.• Temperature
Chemical	<ul style="list-style-type: none">• Geochemical reactions that result in the precipitation of minerals e.g. iron aluminium or calcium carbonate growth;• Aquifer matrix dissolution (can also work to increase hydraulic conductivity);• Ion exchange;• Ion adsorption;• Oxygen reduction.• Formation of insoluble scales.• Formation dissolution
Mechanical	<ul style="list-style-type: none">• Entrained air/gas binding (includes nitrogen &/or methane from microbiological activity).• Hydraulic loading causing formation failure, aquitard failure or failure of casing around joints or seals.
Biological	<ul style="list-style-type: none">• Algae growth and accumulation of biological flocs.• Microbiological production of polysaccharides.• Bacterial entrainment and growth

Source: R Martin, 2012. Clogging issues associated with managed aquifer recharge methods

Physical clogging

- Energy sources include nutrients and carbon in recharge water, sulphur and iron.
- Accumulation / Injection of organic and inorganic suspended solids.
- Velocity induced damage e.g. migration of interstitial fines such as illite or smectite.

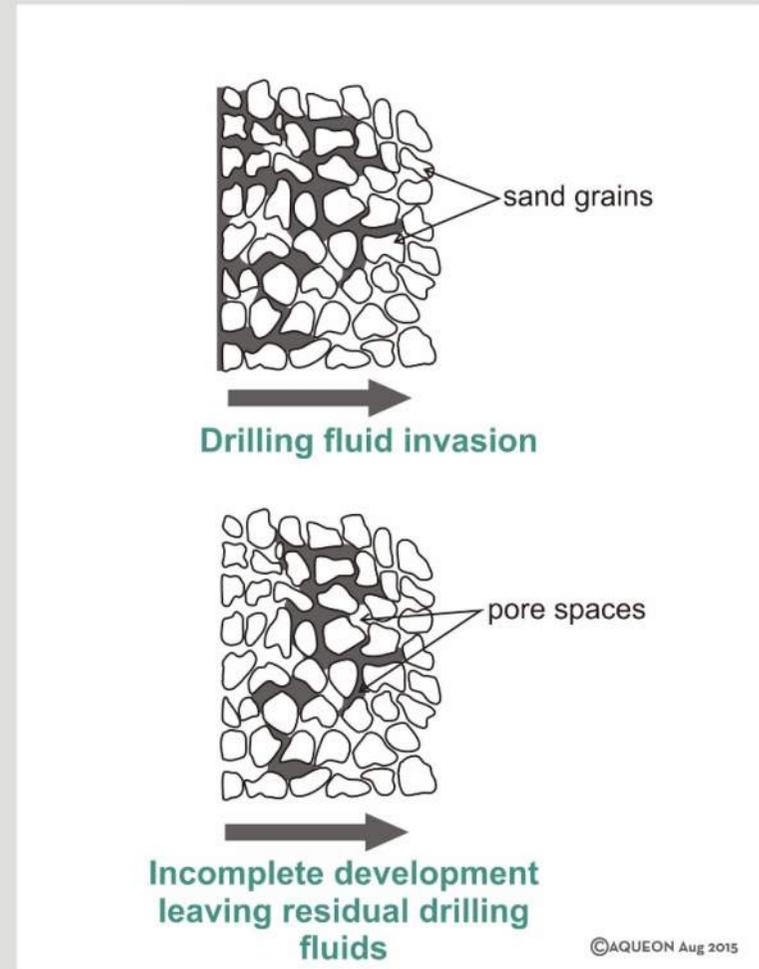


Low Velocity

High Velocity

Mud invasion

- Invasion of drilling fluids (emulsifiers)
- Muds are designed to bridge the pores to form a filter cake to keep pore fluids in place and stabilise the hole.
- Smaller particles can invade further into the pore spaces driven under the differential hydrostatic pressures between the drilling mud and aquifer.



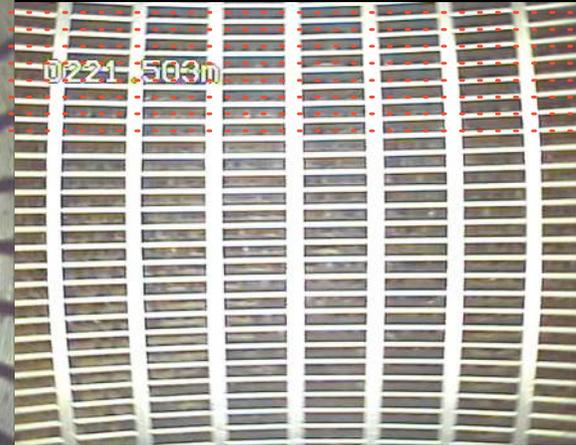
Mud invasion



Poor mud control and development resulting in clogging of screen

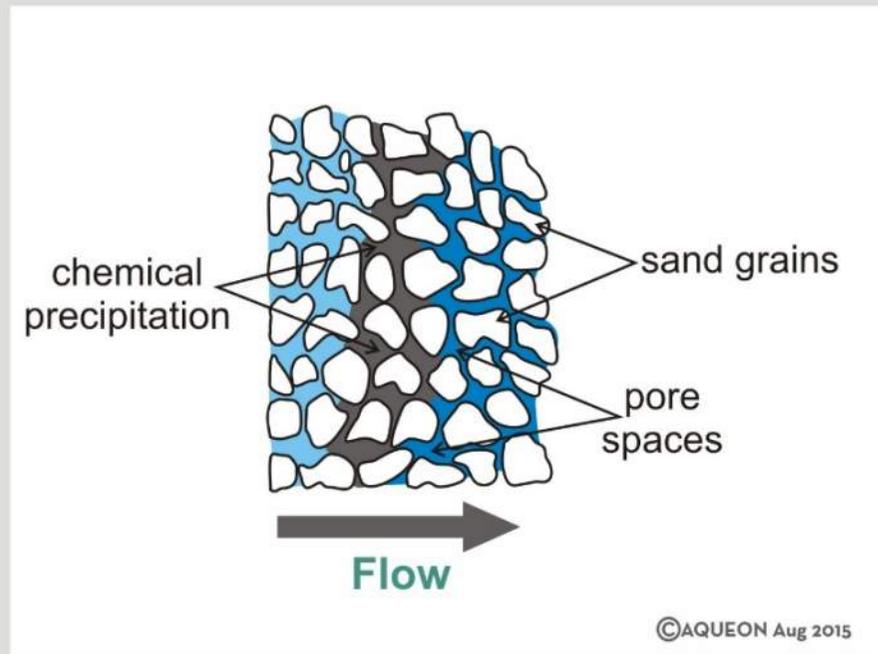


Correct development of screen following construction



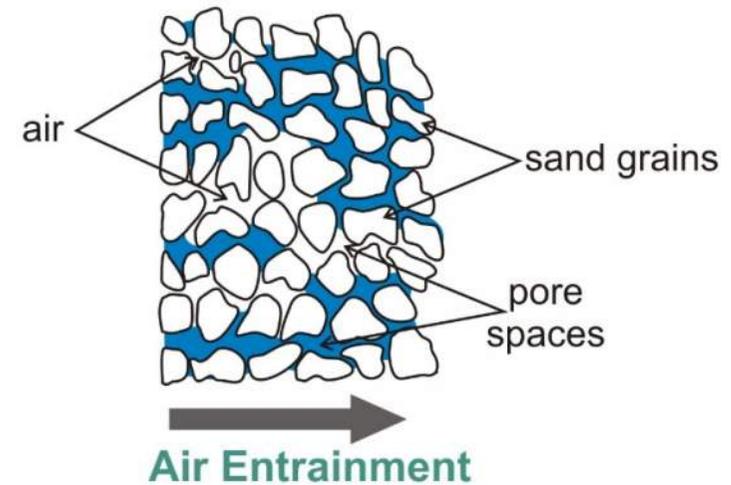
Chemical clogging

- Geochemical reactions that result in:
 - The precipitation of minerals e.g. iron, aluminium or calcium carbonate growth
 - Aquifer matrix dissolution (can also work to increase hydraulic conductivity)
 - Ion exchange
 - pH
 - Ion adsorption
 - Oxygen reduction; or
 - Formation of insoluble scales.



Mechanical clogging

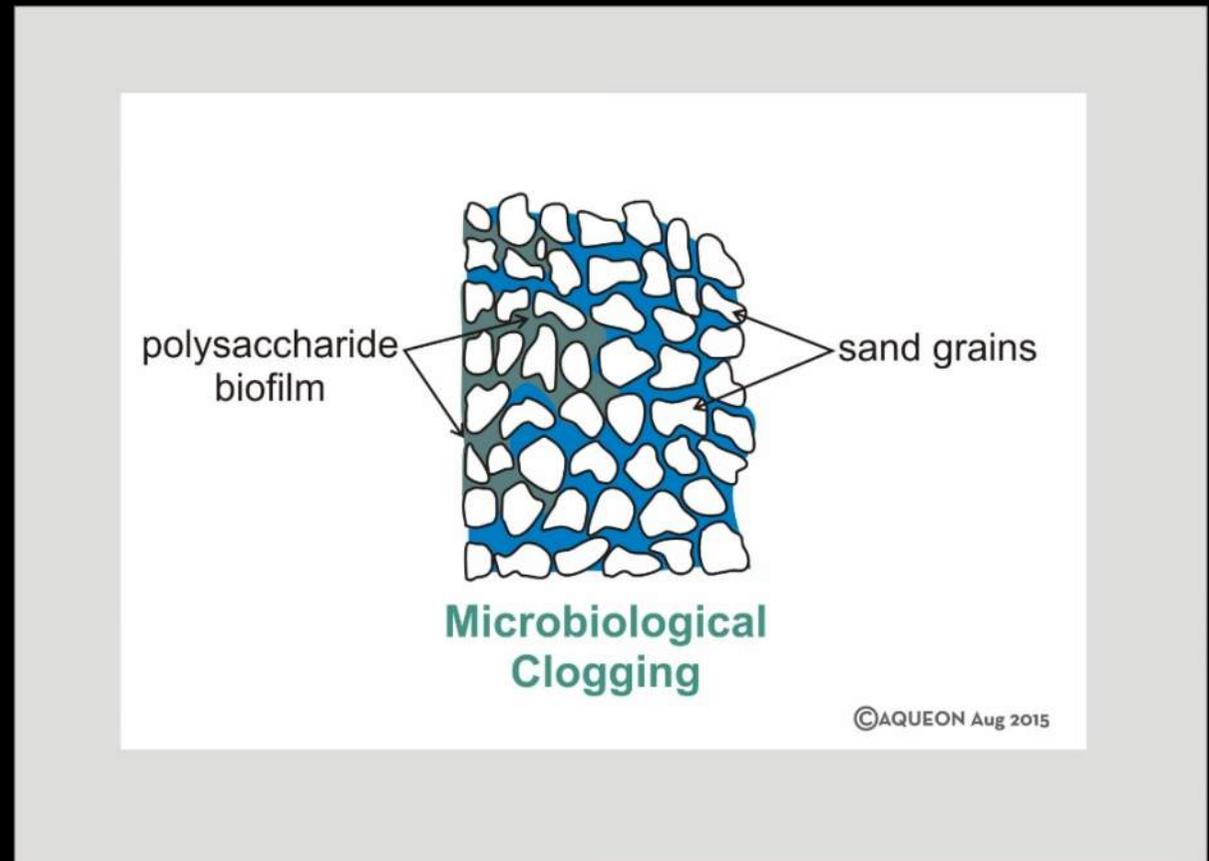
- Entrained air/gas binding (includes nitrogen &/or methane from microbiological activity).
- Hydraulic loading causing formation failure, aquitard failure or failure of casing around joints or seals.



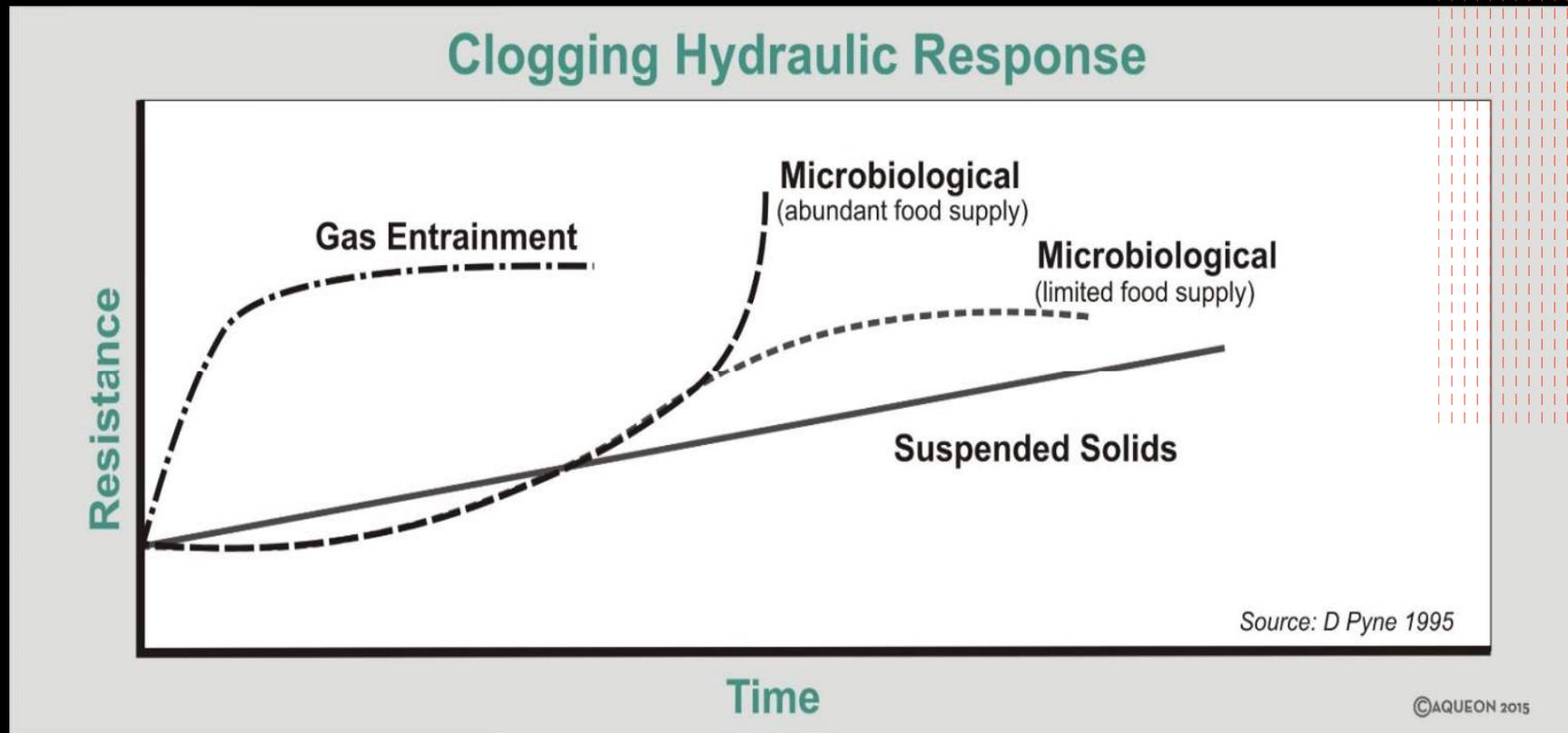
©AQUEON Aug 2015

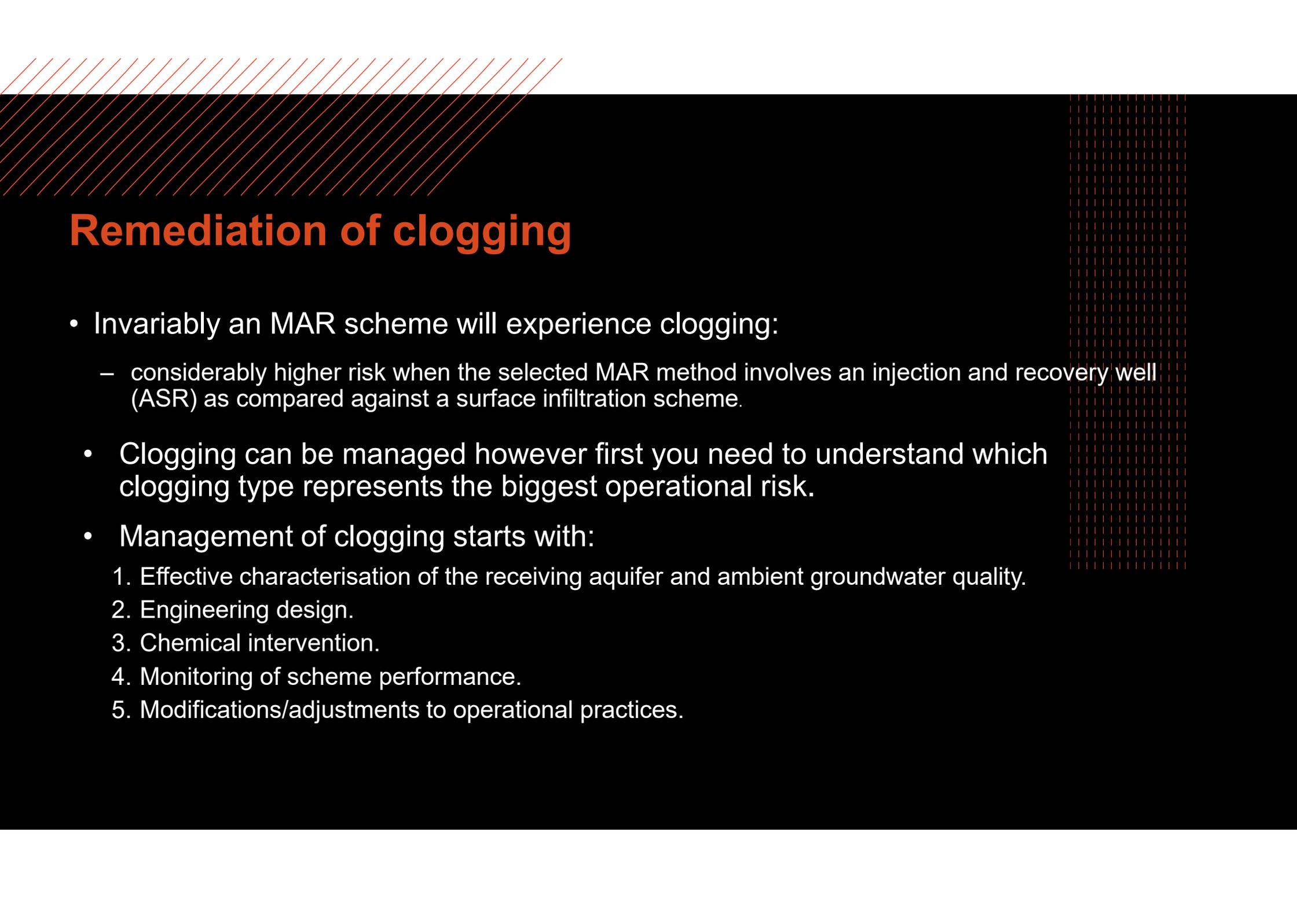
Biological clogging

- Microbiological production of polysaccharides.
- Bacterial entrainment and growth.
- Algae growth and accumulation of biological flocs (mainly associated with infiltration basins).



Clogging hydraulic response





Remediation of clogging

- Invariably an MAR scheme will experience clogging:
 - considerably higher risk when the selected MAR method involves an injection and recovery well (ASR) as compared against a surface infiltration scheme.
- Clogging can be managed however first you need to understand which clogging type represents the biggest operational risk.
- Management of clogging starts with:
 1. Effective characterisation of the receiving aquifer and ambient groundwater quality.
 2. Engineering design.
 3. Chemical intervention.
 4. Monitoring of scheme performance.
 5. Modifications/adjustments to operational practices.

Water pre-treatments to minimise clogging

- Wide range of technologies:
 - Strainers
 - Filtration
 - Sand (gravity pressure)
 - Ring, bag filters
 - Spin filters
 - Micro / Ultrafiltration
 - Disinfection
 - Chlorine
 - Chloramine
 - Chlorine dioxide
 - Ozone
 - UV treatment
 - Chemical treatment



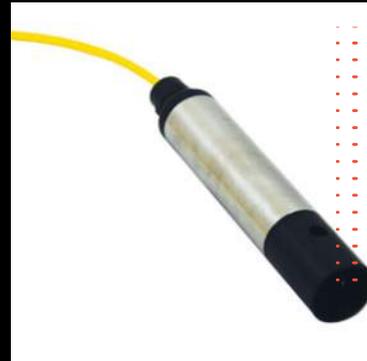


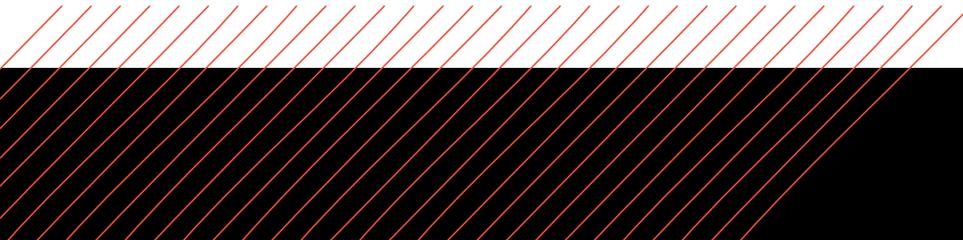
Clogging in injection bores

- Clogging generally occurs close to the screen and gravel pack
- The same clogging processes occur in bores where open hole construction is used but open hole completion presents simpler and quicker remediation options.
- Remediation methods to address clogging are very site specific:
 - what works in one hydrogeological setting may not always be successful in another location;
 - remediation approaches may differ between injection bores across the same scheme and in the same aquifer.
- Remediation methods include:
 - Mechanical techniques
 - Physical techniques
 - Chemical techniques

Monitoring to detect clogging

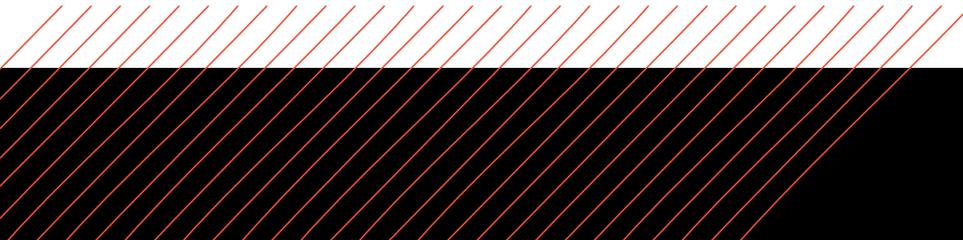
- Injection rate versus pressure response
- Inline turbidity
- Inline EC
- Inline flow meters
- Hydraulic responses in monitoring bores





Operational measures to mitigate clogging

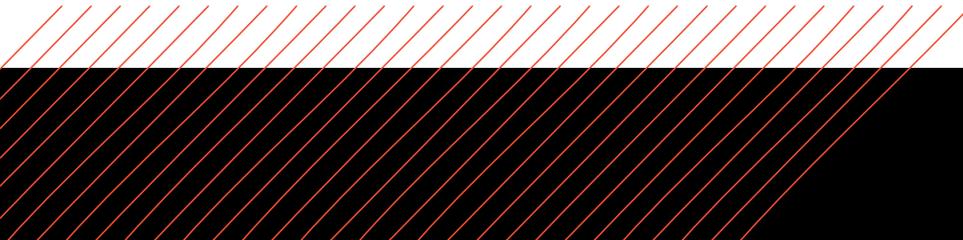
- Flush wellhead piping and well to waste prior to recharge and at beginning of recovery for a few minutes to an hour.
- Periodically backwash well to waste for a few minutes to an hour to remove accumulated solids.
- Typical backflush frequency is every few weeks to every month (depending on source water quality).
- Use same pump for backflush and recovery.
- Prevent clogging by treating water to acceptable standards – often necessary to meet regulatory requirement for protecting groundwater quality and/or existing third party users.



Intervention measures to restore clogged bores - 1

Mechanical techniques

- Back flushing (pumping)
- Intermittent pumping
- Juttering
- Over pumping
- Surging
- Sectional pumping
- Vacuum
- Under reaming
- Ramping up & down of submersible pumps
- Incremental pack redevelopment (Tom Morris ASR Systems)
- High pressure jetting
- Air jetting
- Hydrodynamic fracturing
- Scraping blades and removal of previously injected muddy water
- Dry ice
- Brushing
- High frequency vibration



Intervention measures to restore clogged bores - 2

Physical techniques

- Pasteurization
- Disruption by freezing + pumping
- Ionizing radiation: gamma radiation
- Explosives and ultrasonic

Chemical techniques

- Chlorine & chlorine containing agents
- Acids (hydrochloric acid, sulphamic acid, hydrofluoric acid).
- First chlorine then acid
- Polyphosphates
- Carbon dioxide
- High pressure water jet + hydrogen peroxide + hydrochloric acid to aid enlargement of well diameter.

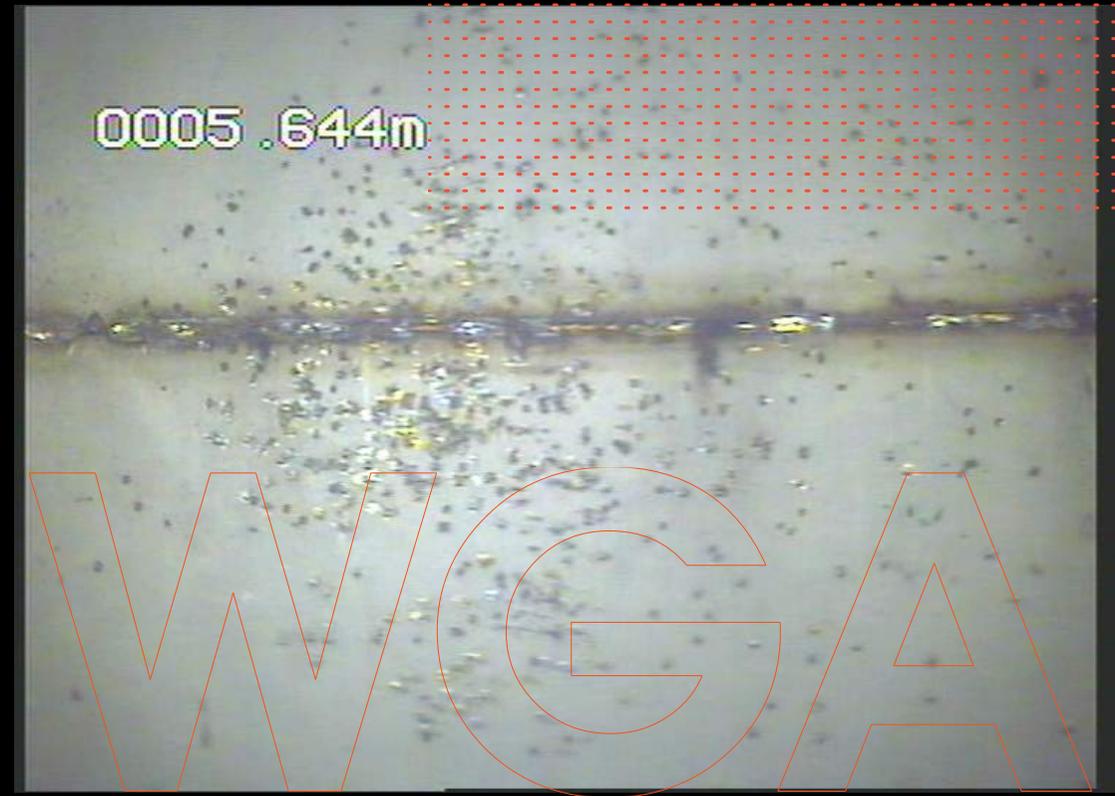
Treatment methods

- Various methods of mechanical pre-treatment can be applied:
 - Passive (wetlands, biofiltration)
 - Filtration ranging from simple sand filters to membrane filters
 - Coagulation and flocculation
 - Activated charcoal
 - UV treatment
 - Chlorination
- Water sourced from RO may require additional buffering before recharge.
- Water sourced from wastewater treatment also may require additional treatment prior to recharge (e.g. algae management chlorination – THM?).



Design Considerations

- Experience in the design and construction of these complex systems.
- Understanding of the whole system not the individual parts.
- Consider access for maintenance.
- Safety in Design.
- Materials consideration (plastic vs steel).
- Mechanical & Electrical.
- Operation and maintenance – clogging.
- Management of artesian pressures or waterlogging.



Lessons Learned – Planning

- Understanding source water quality and quantity is critical for the project design
- Understanding demands (timing) informs MAR design
- Engage early and often with regulators
- Communicate what the drivers are as often as possible
- Identify how the system will be operated
 - Must do this at the start
- Business case and economic assessment



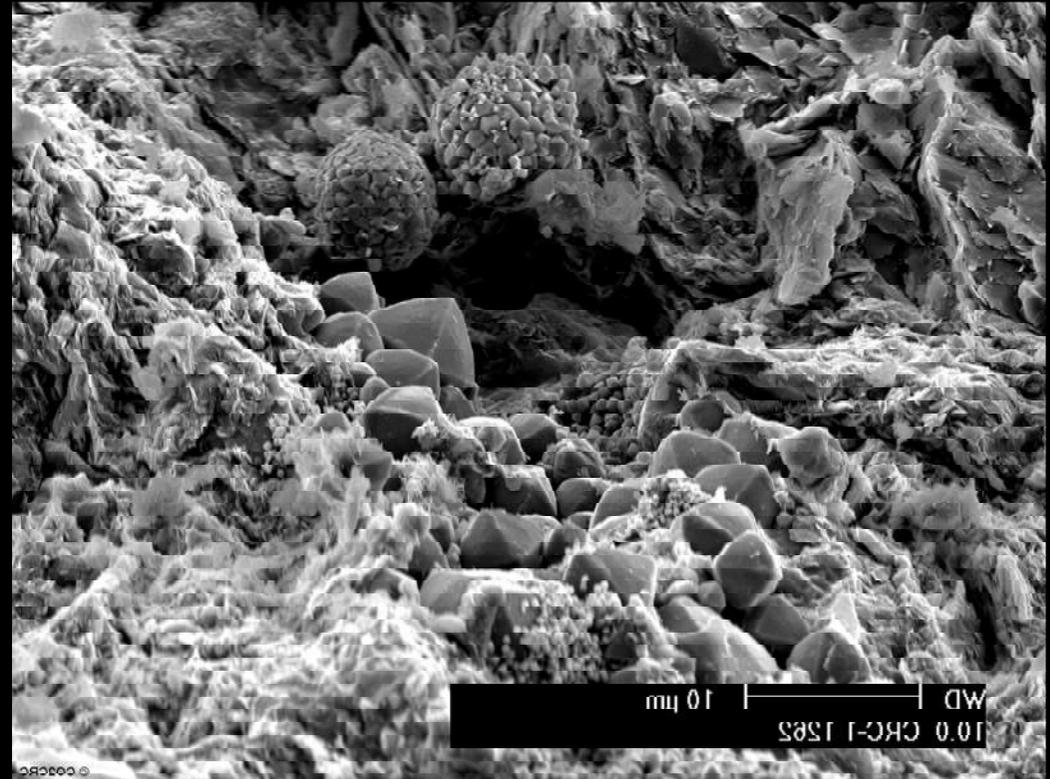
Lessons Learned – Policy & Economics

- Policy changes may unintentionally compromise operations of the MAR system.
- Policy around MAR systems must be adaptable to suit different operating conditions.
- Guidelines must be clear and revisited/updated at least every five years .
- Don't underestimate the time it takes to get approvals.



Lessons Learned – Investigations

- Apply a structured investigation program
- Develop investigations around risks and knowledge gaps
- Field Investigation is 20% to 25% of the total capital cost of the project but the project relies 100% on the outcomes of the field Investigation.
- DO NOT SACRIFICE FIELD INVESTIGATIONS UNDER THE ILLUSION OF SAVING COSTS
- There are NO shortcuts
- Investigations inform infrastructure design



SEM showing kaolinite lining pores

Field Investigations

- Aquifer is the Key to the successful operation of the whole system.
- Critical for successful operation that it is adequately characterised.
- Clogging will happen
 - Physical
 - Chemical
 - Mechanical
 - Biological
 - Clogging can be managed



Bore Construction – Lessons Learned

- Not a “simple” production bore!
- Consider
 - Construction material selection
 - Drilling method and good mud control
 - Proper completion
 - Proper development
- Unlike production bores a bore used for recharge will need to withstand high pressure (potentially up to 1,500 kPa).



Lessons Learned - Community Consultation

- Don't forget it.
- Construction activities will inconvenience residents
 - Dust
 - Noise
 - Parks shut down



Lessons Learned - Construction

- Allow adequate time for proper commissioning and testing of systems.
- Allow for Audits by experienced professionals at critical points in the construction stage.
- Do not compromise on the quality of construction materials to be used



*Installation of down hole flow control valve –
Source R Tribble Cactus Controls*

Lessons Learned - Operations

- Training for operators is vital (early engagement and involvement in system design important)
- Develop detailed monitoring and management plans for the system
- Maintenance plans for the plant and equipment are critical
- Allow for on-going improvement in system as new technologies become available



WGA

WALLBRIDGE GILBERT
AZTEC

Questions

ADELAIDE

60 Wyatt Street
South Australia 5000
Telephone: +61 8 8223 7433

WALLBRIDGE GILBERT AZTEC

www.wga.com.au





Call for Abstracts



Groundwater Resources Association of California and the Arizona Hydrological Society Present:

16th Biennial Symposium on Managed Aquifer Recharge

Recharge to the Rescue! Managed Aquifer Recharge as a Water Management Tool

March 6 to 7, 2018

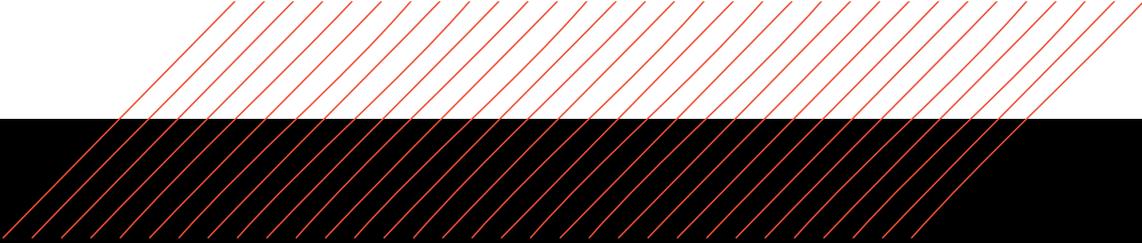
March 5, Optional Workshops

Herman Bower Award

March 6, 2018

The Dana on Mission Bay

San Diego, California, USA



MAR Testing, Design and Construction

- Advanced methods for selection of aquifers, sites and methods
- Designing for storm water capture
- Predicting sediment loading/clogging
- Alternative recharge systems
- Innovation in harvesting and storing flood waters
- Overcoming the hydrogeology/engineering disconnect

MAR Operations and Maintenance

- Monitoring and modeling
- Tracer testing
- Clogging management
- Fate of pathogens and pollutants
- Geochemistry and hydrogeology
- Groundwater hydraulics and storage recovery
- Training for MAR operators
- Long-term maintenance requirements/budgeting
- Modifying operations for long-term sustainability

MAR Governance

- Integrated water resources management
- Recharge policies, standards and regulations
- Community engagement and MAR awareness
- MAR to complement groundwater demand management

- Legal issues related to storm water capture by MAR systems

MAR and Water Resources Management

- Reclaimed water reuse via MAR
- Storm water harvesting via MAR (MS4 permitting, etc.)
- Quantification of benefits and costs of MAR
- MAR for drinking water quality improvement
- MAR with desalinated water
- Mining and industrial applications of MAR
- MAR to source heat pumps and geothermal injection
- Mitigating geological problems using MAR - land subsidence, seawater intrusion, etc.
- MAR for rural and irrigation water supplies
- MAR in conjunctive use of surface water and groundwater

MAR Case Studies

- Success factors for projects that worked
- Lessons learned from projects that did not work

Other Issues related to MAR

- MAR and climate change
- MAR in urban areas
- Greenhouse gas considerations in MAR operations

Abstracts deadline: November 1, 2017.

People. Innovation. Performance.



Fortescue's Papa Waringka Managed Aquifer Recharge Scheme



Disclaimer

Important Notice

The purpose of this presentation is to provide general information about Fortescue Metals Group Limited ("Fortescue"). It is not recommended that any person makes any investment decision in relation to Fortescue based on this presentation. This presentation contains certain statements which may constitute "forward-looking statements". Such statements are only predictions and are subject to inherent risks and uncertainties which could cause actual values, results, performance or achievements to differ materially from those expressed, implied or projected in any forward-looking statements.

No representation or warranty, express or implied, is made by Fortescue that the material contained in this presentation will be achieved or prove to be correct. Except for statutory liability which cannot be excluded, each of Fortescue, its officers, employees and advisers expressly disclaims any responsibility for the accuracy or completeness of the material contained in this presentation and excludes all liability whatsoever (including in negligence) for any loss or damage which may be suffered by any person as a consequence of any information in this presentation or any error or omission therefrom.

Fortescue accepts no responsibility to update any person regarding any inaccuracy, omission or change in information in this presentation or any other information made available to a person nor any obligation to furnish the person with any further information.

Additional Information

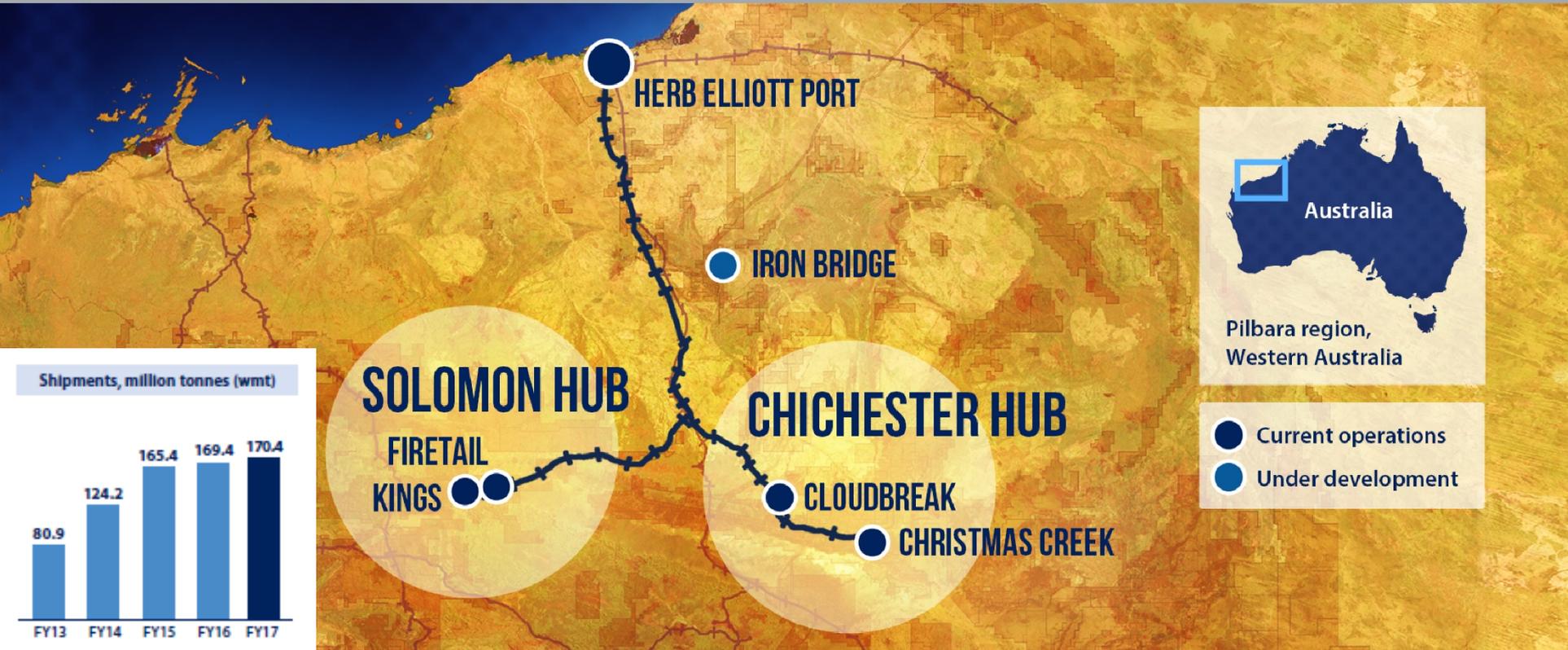
This presentation should be read in conjunction with the Annual Report at 30 June 2016 together with any announcements made by Fortescue in accordance with its continuous disclosure obligations arising under the Corporations Act 2001.

Any references to reserve and resources estimations should be read in conjunction with Fortescue's Ore Reserves and Mineral Resources statement for its Hematite and Magnetite projects at 30 June 2016 as released to the Australian Securities Exchange on 19 August 2016, and ASX releases dated 20 May 2014 and 8 January 2015 as they relate to Hematite Mineral Resources Development Properties. Fortescue confirms in the subsequent public report that it is not aware of any new information or data that materially affects the information included in the relevant market announcement and, in the case of estimates of mineral resources or ore reserves, that all material assumptions and technical parameters underpinning the estimates in the relevant market announcement continue to apply and have not materially changed.

All amounts within this presentation are stated in United States Dollars consistent with the functional currency of Fortescue Metals Group Limited, unless otherwise stated. Tables contained within this presentation may contain immaterial rounding differences.

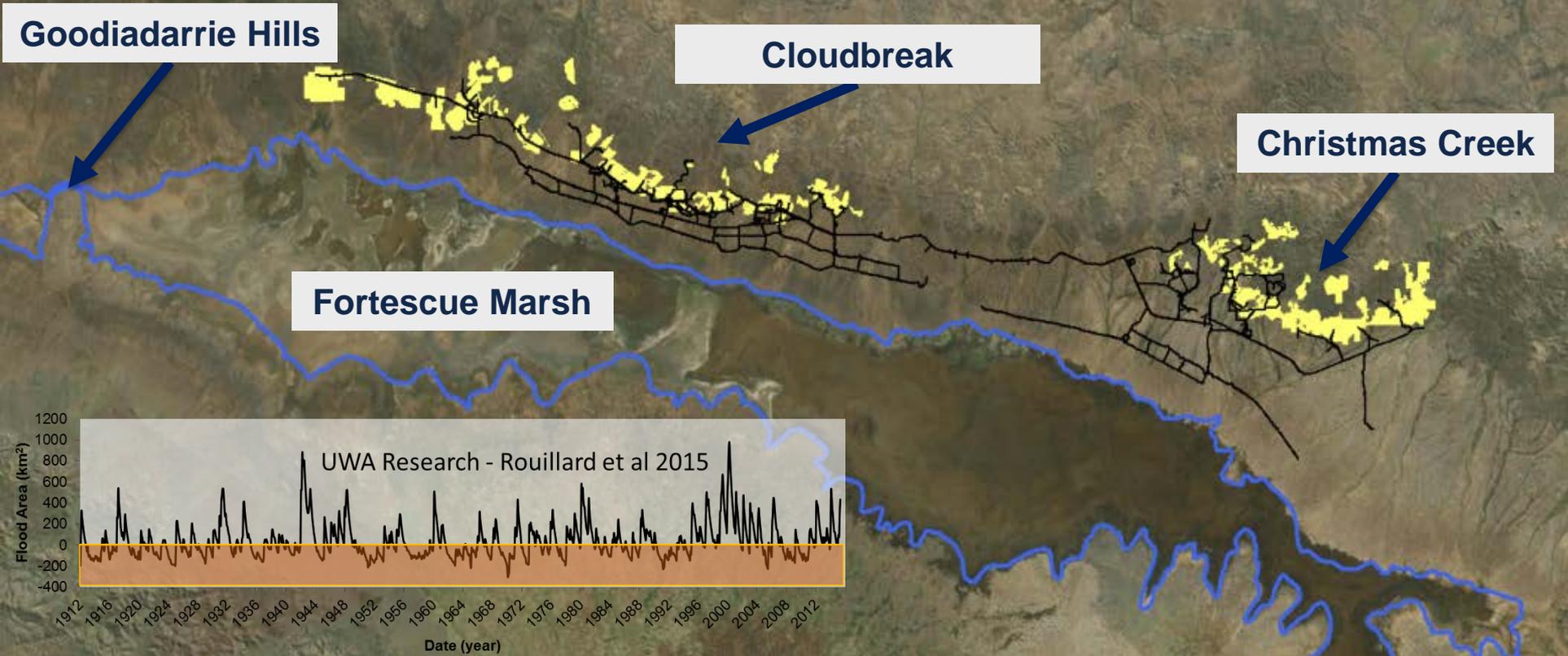
Fortescue's Operations

Mining Hubs



Environmental Setting

1000km² ephemeral wetland (evaporation basin)



Ecological Significance

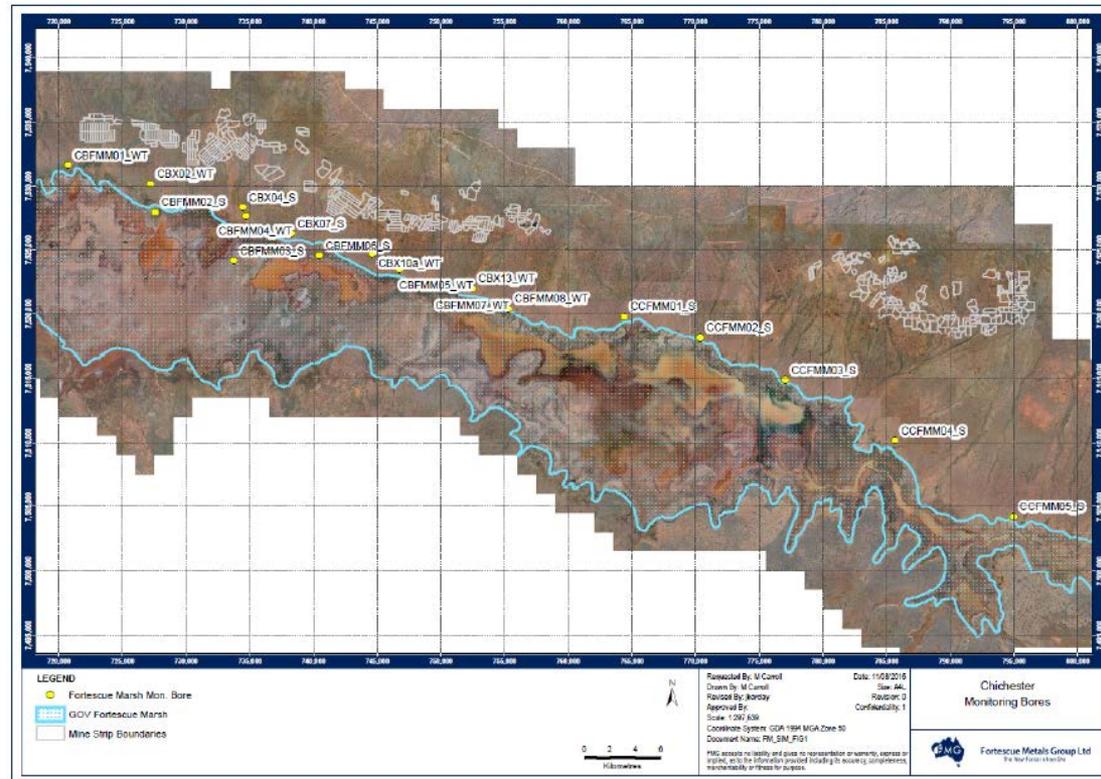


- Chichester Operations are located to the North of the **Fortescue Marsh**.
- Conditions of Environmental Approval requires protection of **water table levels** adjacent to the Marsh.
- Maintaining Marsh groundwater levels is the **primary function** of the MAR scheme.

Environmental Setting

Ecological Significance

- Groundwater levels near **Fortescue Marsh** are monitored at 12 multi level monitoring bores.
- Monitoring bores are spread across **80 km**.
- The water levels in the shallow water table aquifer must be maintained within **+/- 1m of range** of baseline water levels.
- Deep monitoring bores are used to assess **potential impacts** to shallow aquifer.



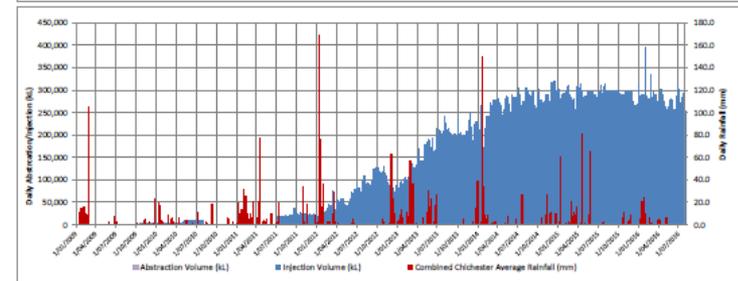
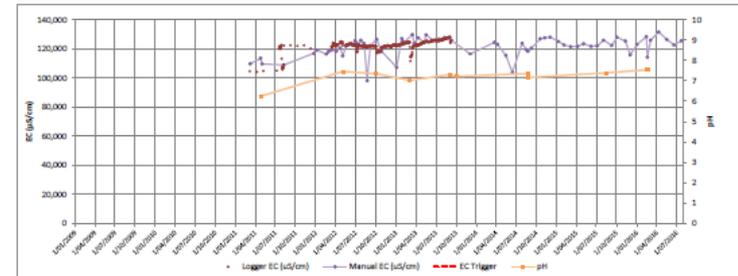
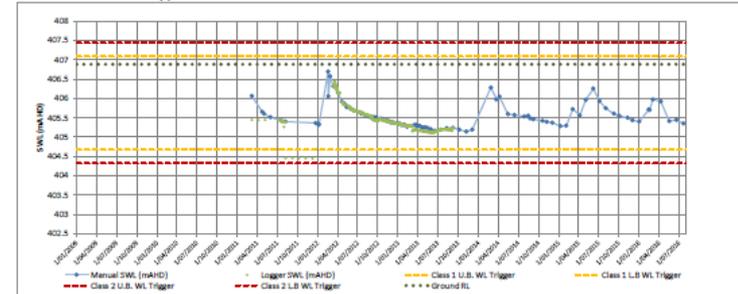
Marsh Monitoring

MS conditions

- Part IV approval under the EP act requires Fortescue to maintain water levels within +/- 1m of baseline water levels.
- Baseline is based on monitoring since 2006 and has been updated with a study by UWA.
- Water levels are observed to be very sensitive to flood levels of the Fortescue Marsh and do not respond to injection in the deep confined aquifer.

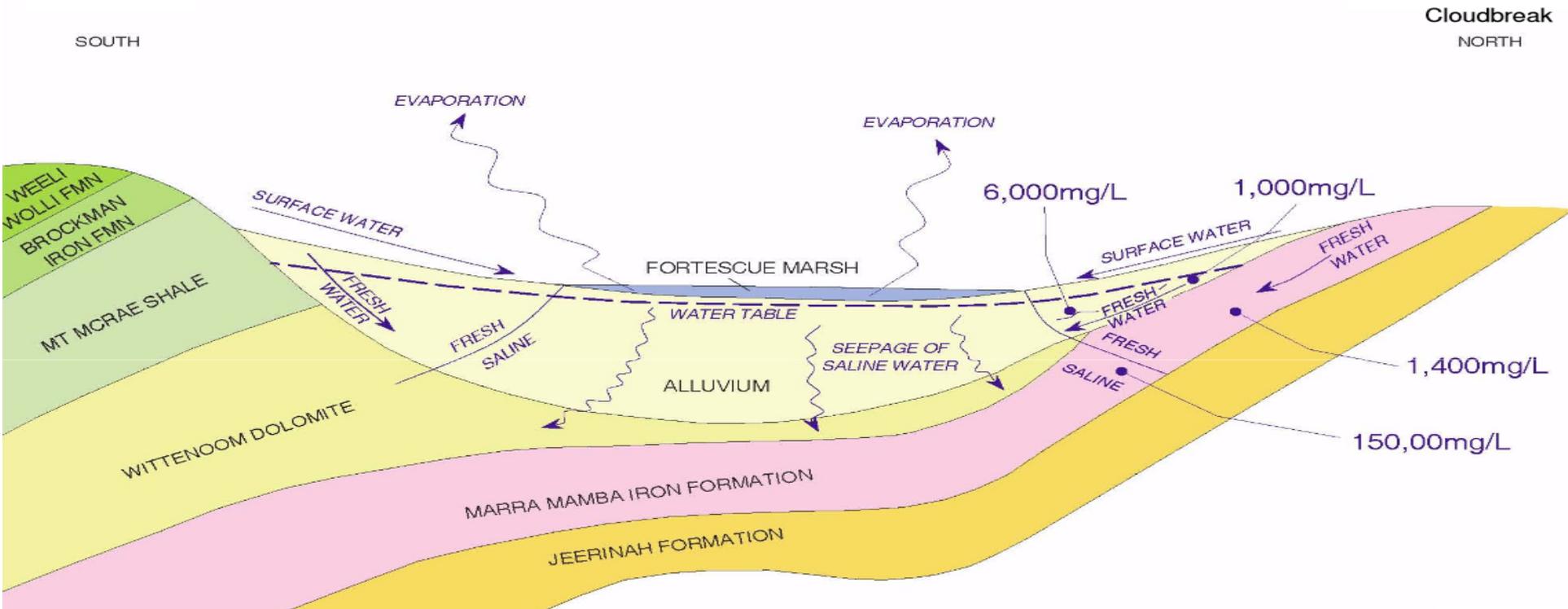
CBFMM02_S Hydrograph

Bore Name: CBFMM02_S Monitored Aquifer: Upper TD.
 Inj. Totals: Saline Injection Management Zone: Zone A
 Abs. Totals: Not applicable

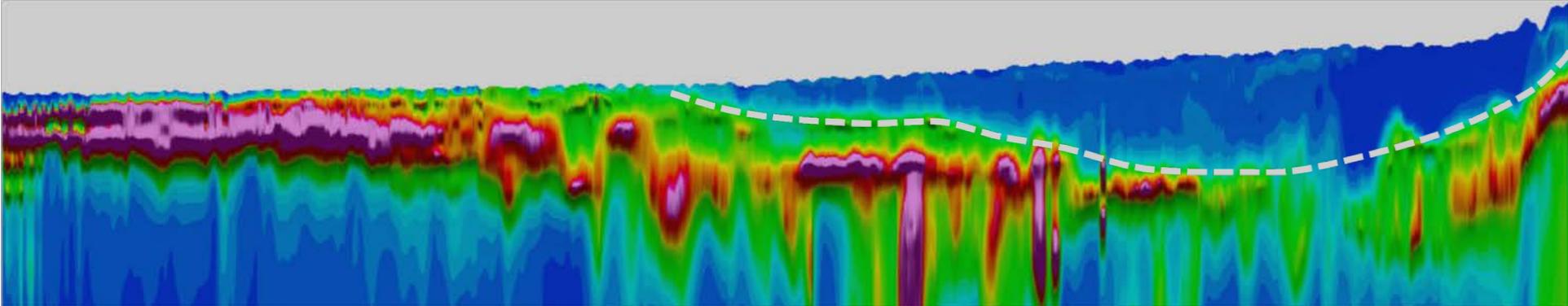


Hydrogeological Setting

Complex array of alluvial aquifers of variable quality - fresh to hypersaline



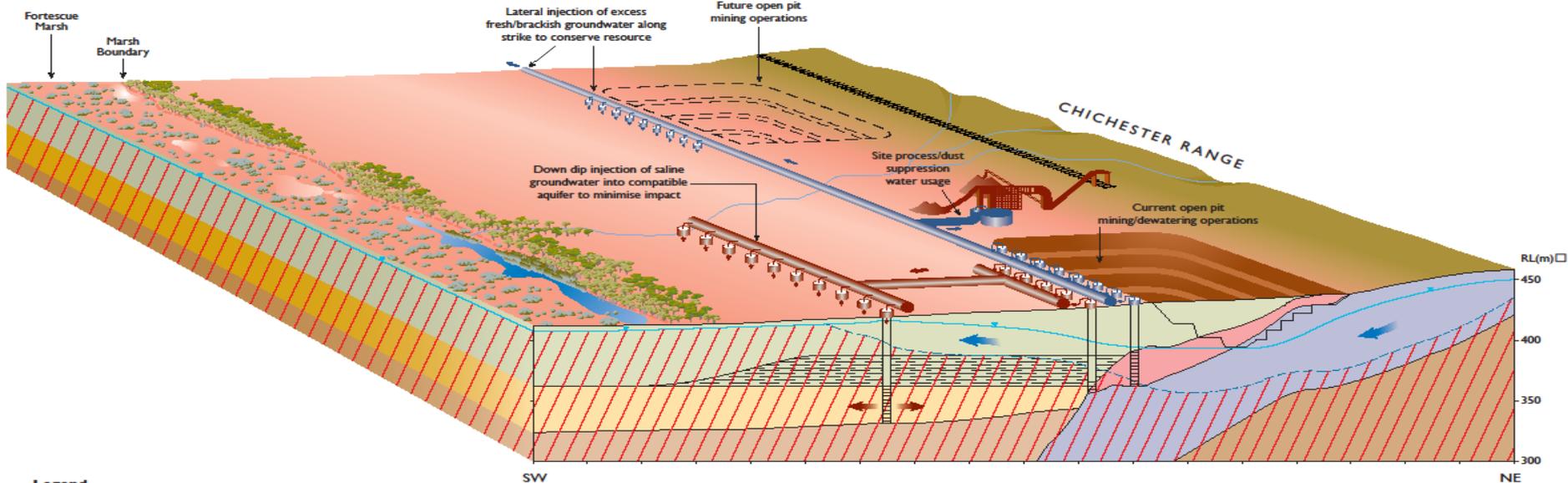
Resistivity Survey



- SkyTEM was used to identify the saline interface.
- Resistivity contrasts identified that are consistent with the site conceptual model.
- Identified conductive geological units and/or conductive water.
- Saline water is more dense than brackish. **Density driven** flow versus **topographically driven** flow.

MAR Scheme

Enabling below watertable mining, mitigating environmental impacts and ensuring regulatory compliance



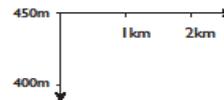
Legend

-  Alluvium/Colluvium
-  Quaternary Clays
-  Oakover Formation
-  Wittenoom Formation
-  Mineralised Marra Mamba
-  Marra Mamba Formation
-  Jeerinah Formation

-  Pumping/Injection Bores
-  Fresh/Brackish Water Management Infrastructure
-  Saline Water Management Infrastructure

-  Water Table
-  Fresh/Brackish Groundwater System
-  Saline Groundwater System

Scale



Chichester Dewatering

Global Perspective



Diavik Mine, NWT Canada –
Surrounded by water, pumping at
450L/s

Porgera Mine, PNG –
Precipitation of 3,200mm/yr,
pumping at **300 L/s**



Chichester Mines – 300mm/yr in
a desert and we are pumping
over **6,000 L/s!**

Geology rules

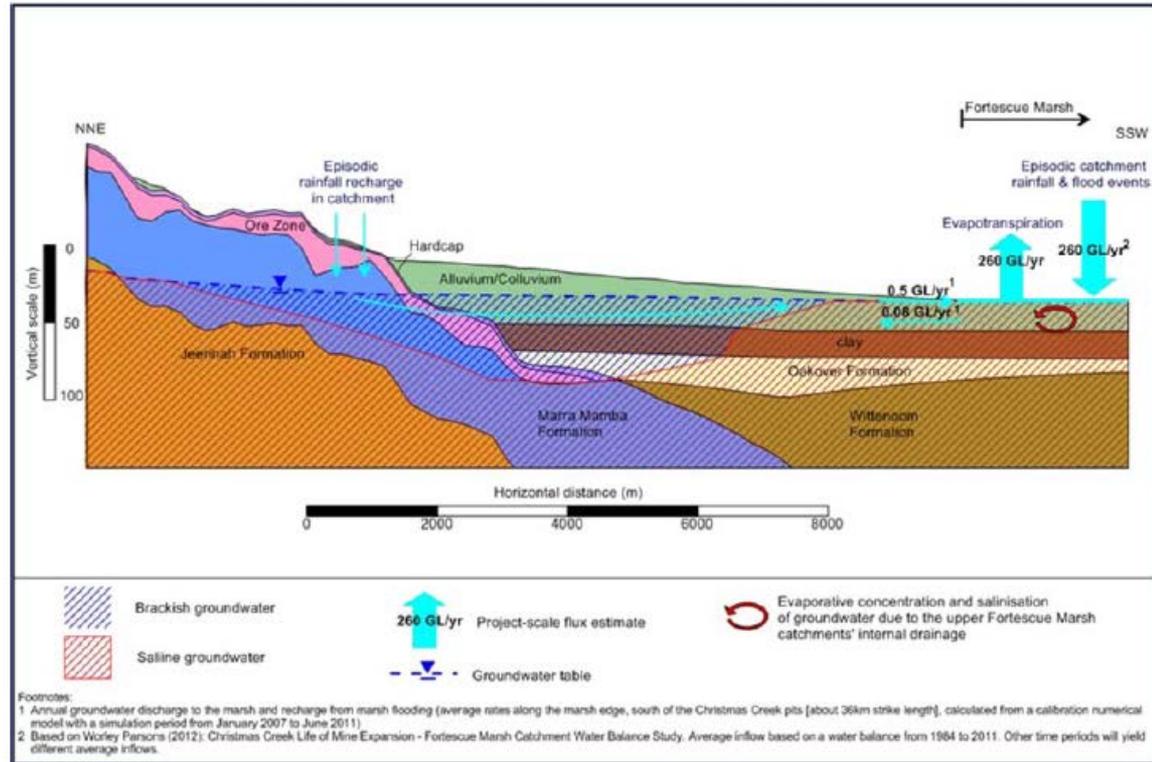
- Dewatering rates are controlled by the **hydraulic conductivity** of the geology.
- Incredibly large permeability in the mineralized Marra Mamba (ore zone - abstraction) and Oakover formation (saline injection).
- There is connection between the abstraction and injection areas, which results in some **recirculation** of water.

Hydro-stratigraphic unit	Hydraulic conductivity		Specific yield (-)	Specific storage coefficient (1/m)
	K _h (m/day)	K _v (m/day)		
Alluvial clay	0.01 (0.01)	0.0006 (0.001)	0.04 (0.01)	5 x 10 ⁻⁴ (10 ⁻⁶)
Oakover Formation	250 (200)	25 (20)	0.1 (0.04)	5 x 10 ⁻⁵ (10 ⁻⁶)
Oakover Formation (at MMB intersection)	0.01 - 60 (N/A)	(0.001 - 6) (N/A)	0.04 (N/A)	5 x 10 ⁻⁵ (N/A)
Lower Tertiary Detrital	0.1 (N/A)	5 x 10 ⁻³ (N/A)	0.04 (N/A)	10 ⁻⁴ (N/A)
Wittenoorn Formation	1 (3)	0.1 (0.3)	0.02 (0.005)	10 ⁻⁵ (10 ⁻⁶)
Mineralised Marra Mamba Formation	35 - 60 (60)	3.5 - 6 (1.2)	0.15 (0.03)	5 x 10 ⁻⁴ (10 ⁻⁵)
Fractured Un-mineralised Marra Mamba Formation	10 - 60 (5)	1 - 6 (0.05)	0.15 (0.03)	5 x 10 ⁻⁴ (10 ⁻⁵)
Un-mineralised Marra Mamba Formation	1 (0.5)	0.1 (0.01)	0.12 (0.01)	10 ⁻⁵ (10 ⁻⁶)
Fractured Roy Hill Shale	5 (N/A)	0.5 (N/A)	0.12 (N/A)	10 ⁻⁵ (N/A)
Roy Hill Shale	0.01 (0.01)	0.0001 (0.001)	0.01 (0.001)	10 ⁻⁵ (10 ⁻⁶)

Chichester Dewatering

Conceptual Model

- High permeability in the Marra Mamba.
- Relatively low permeability in the Jeerinah.
- Very high permeability in the Oakover.
- Oakover is confined by a Tertiary clay unit.
- Moderate connection between Marra Mamba and Oakover.



PRODUCTION BORE LOG

BOREHOLE NUMBER
NFP26

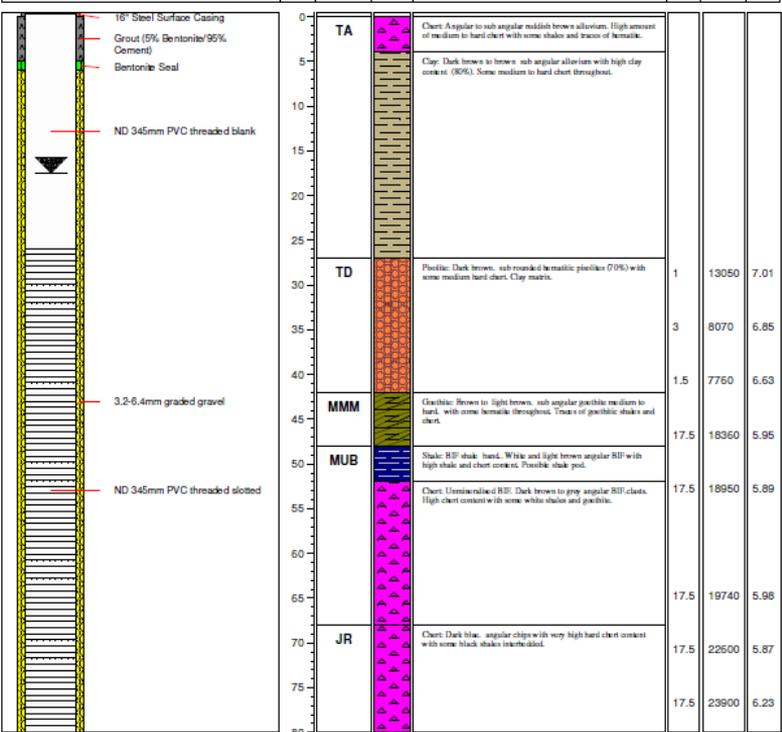


Fortescue Metals Group Ltd
Level 2, 87 Adelaide Terrace
East Perth, WA 6004
PH: 08 82188888 FAX: 08 82188880

PROJECT NAME: NOR_SOUTH_BF_phase1
LOCATION: Cloudbreak
DRILLING CO: FMG
DRILLING METHOD: DualRotary/Conv
LOGGED BY: Adam Lever
FIELD BOOK NO:
EASTING: 735450.798
NORTHING: 7531737.424
ELEVATION (mAHD): 420.157
DATE BEGUN: 28/07/2017 DATE COMPLETED: 30/07/2017

FINAL BORE DETAILS	
Drilled Depth (mbgl):	80
Cased Depth (mbgl):	79.91
Stick Up (magl):	0.36
Airlift Yield (L/s):	12
Water Level (mbgl):	17.45
Quality - pH & EC (uS/cm):	6.67 31900

BORE CONSTRUCTION	DEPTH (mbgl)	STRATIGRAPHY	LITHOLOGY	DESCRIPTION	YIELD (L/s)	EC (uS/cm)	pH
-------------------	--------------	--------------	-----------	-------------	-------------	------------	----



Abstraction bores are screened from first water strike to end of hole.

Injection bores sealed at the top of the Oakover and drilled open hole to depth.

PRODUCTION BORE LOG

BOREHOLE NUMBER
SRP192

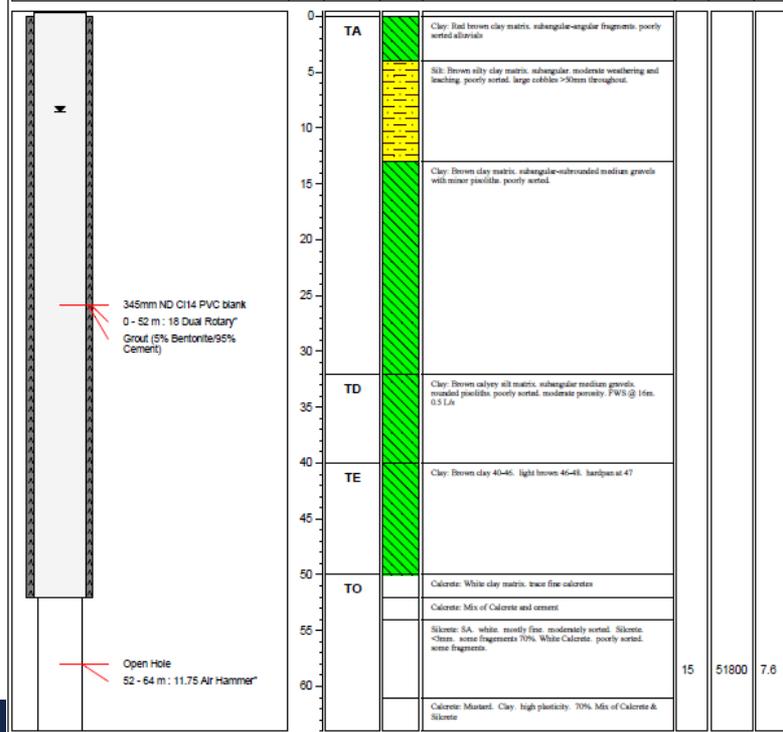


Fortescue Metals Group Ltd
Level 2, 87 Adelaide Terrace
East Perth, WA 6004
PH: 08 82188888 FAX: 08 82188880

PROJECT NAME: Saline Zone H
LOCATION: Cloudbreak
DRILLING CO: FMG
DRILLING METHOD: DualRotary/RC
LOGGED BY: Ludovic Sprauer
FIELD BOOK NO:
EASTING: 732465.221
NORTHING: 7531133.472
ELEVATION (mAHD): 416.994
DATE BEGUN: 5/10/2015 DATE COMPLETED: 12/10/2015

FINAL BORE DETAILS	
Drilled Depth (mbgl):	64
Cased Depth (mbgl):	52
Stick Up (magl):	0
Airlift Yield (L/s):	15
Water Level (mbgl):	8.49
Quality - pH & EC (uS/cm):	7.6 51800

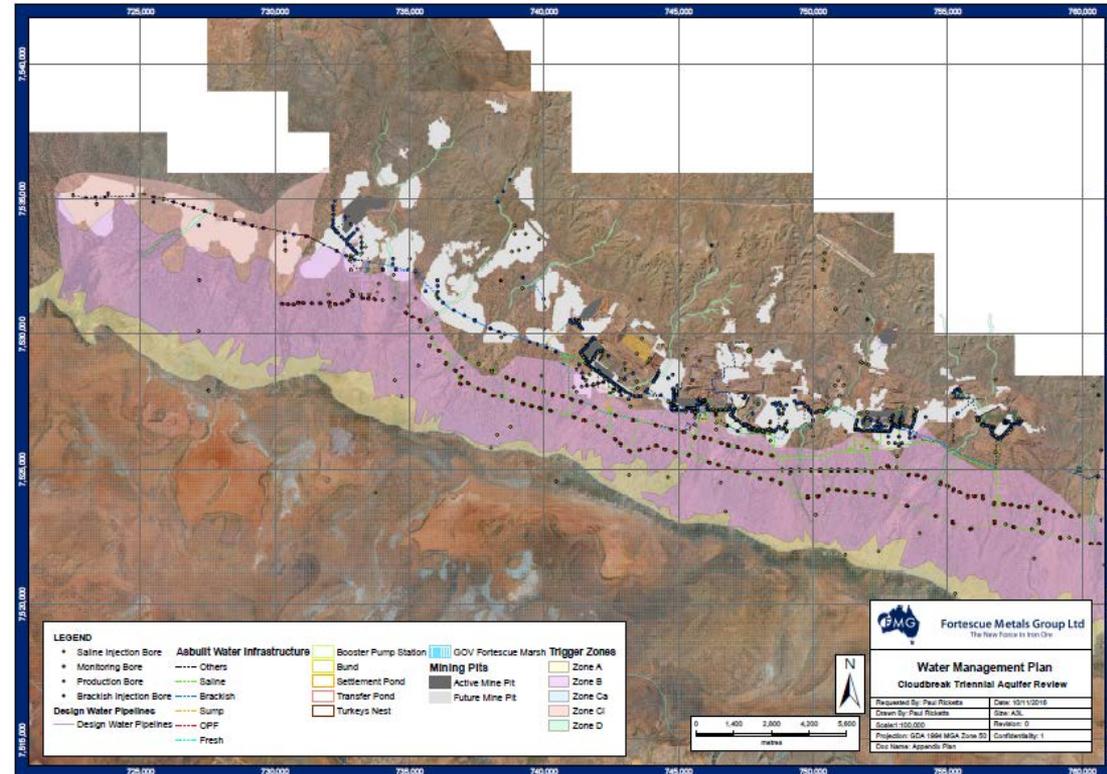
BORE CONSTRUCTION	DEPTH (mbgl)	STRATIGRAPHY	LITHOLOGY	DESCRIPTION	YIELD (L/s)	EC (uS/cm)	pH
-------------------	--------------	--------------	-----------	-------------	-------------	------------	----



Water Management System

Cloudbreak – 150 GLA

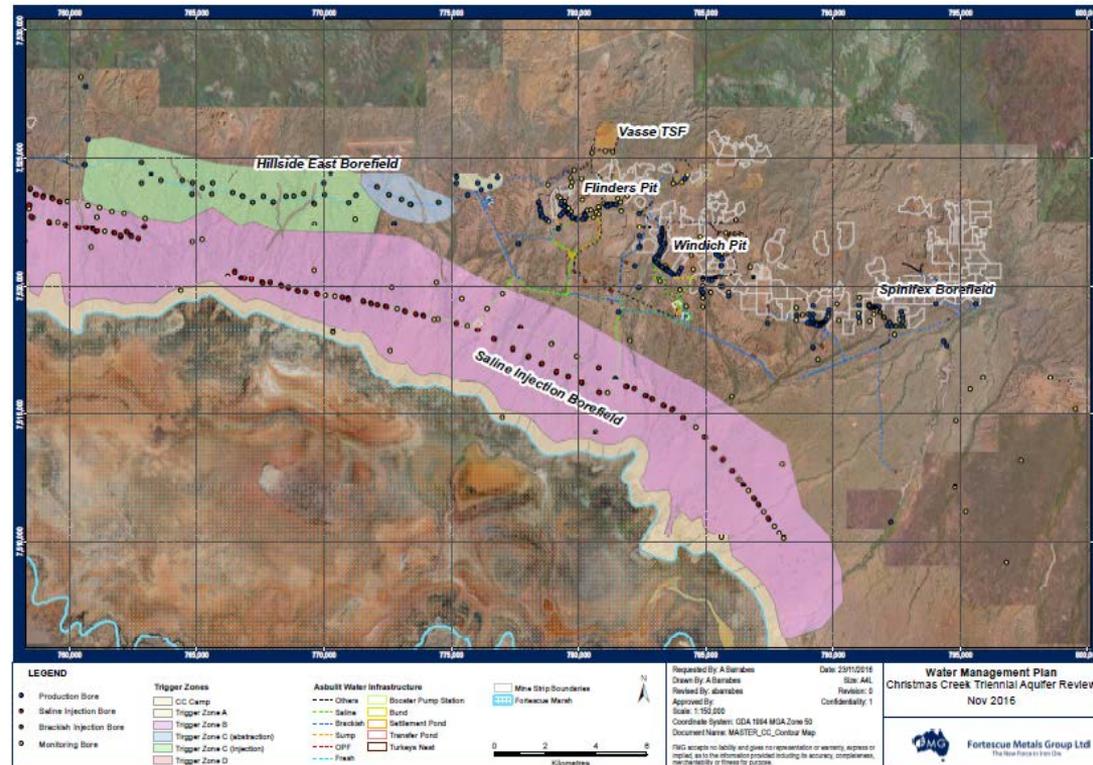
- 500 km pipework
- 630 production bores
- 1185 monitoring bores
- 84 brackish injection bores
- 188 saline injection bores
- Capable of moving around 200 GLA



Water Management System

Christmas Creek – 50 GLA (110 GLA approved)

- 500 km pipework
- 630 production bores
- 1185 monitoring bores
- 84 brackish injection bores
- 188 saline injection bores
- Capable of moving around 200 GLA



Extensive Water Management System

Abstraction



Transfer

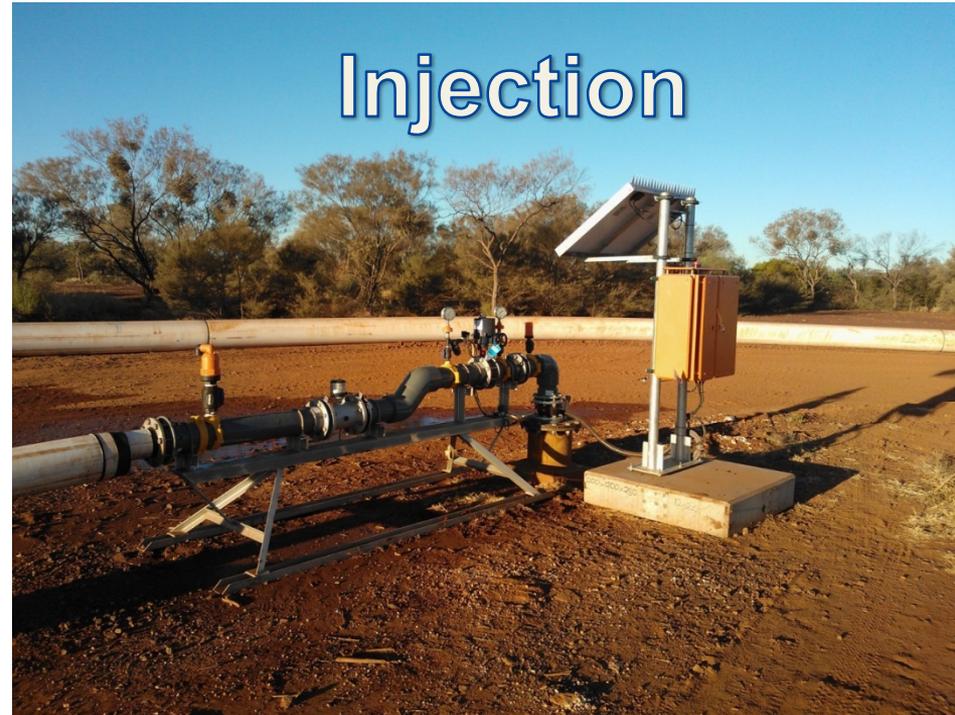


Extensive Water Management System

OPF Water Supply

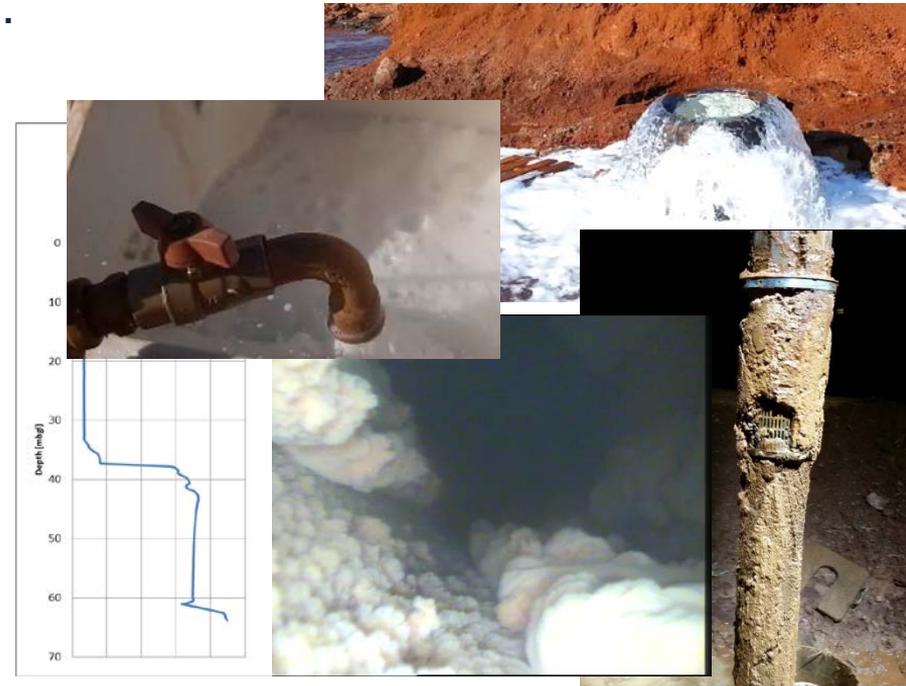


Injection



Lessons Learned

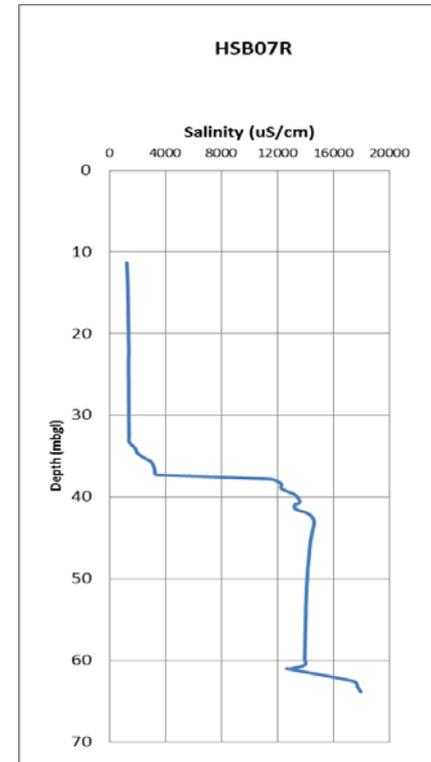
- Dealing with large scale dewatering and reinjection has resulted in several unusual conditions and lessons learned.
 - Brackish injection and recovery
 - Density contrast
 - Degassing
 - Iron bacteria
 - Oxide precipitate
 - Bore clogging and rehabilitation
 - Upwards gradients



Brackish injection and recovery

Brackish/Saline Interface

- Ore processing requires brackish quality water to minimise the potential impurities to ore product and reduce corrosion in the plant.
- Brackish water is used as dust suppression in non-mining areas.
- Dewatering in new areas typically starts with brackish abstraction and trends to saline abstraction.
- Surplus at start and transitions to deficit.
- Injected 26 GL of brackish water.
- Recovered 24 GL of previously injected brackish water.
- Required relatively low pumping rates and drawdown to avoid saline upconing.



Hypersaline versus Brackish

- Saline injection capacity testing indicated very high injection rates.
- Initial production capacity was far lower than tested.

Why?

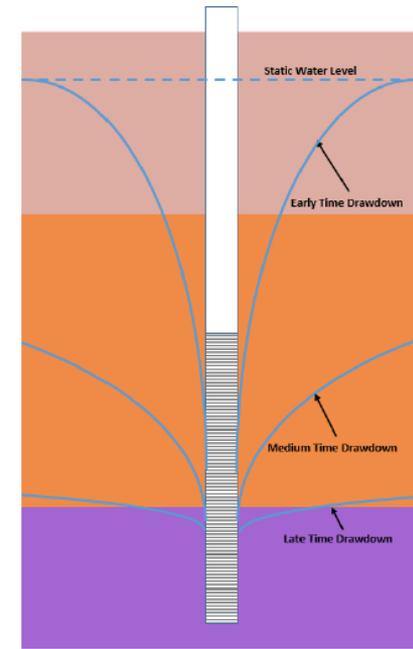
- Contrast in density between injected water and aquifer water was on the order of 3 to 4m head. Static water level is approximately 10m below ground level. Lost ~50% injection capacity.

Solution

- Bores were retrofitted to allow for pressure injection. System can allow for injection up to 20m head above ground level.

“Air in Bores”

- Dewatering operators could not achieve target pumping water levels due to “air in bores”.
 - Cavitation
 - Vortexing
 - Low water level
 - Air in aquifer
 - Cascading
 - Degassing
- Investigation was conducted. Gas samples were collected.
- Gas was determined to be CO₂
- Cause: rapid reduction in pressure from dewatering cause degasification of CO₂
- Solution: Aim for gradual and even drawdown across the borefield.

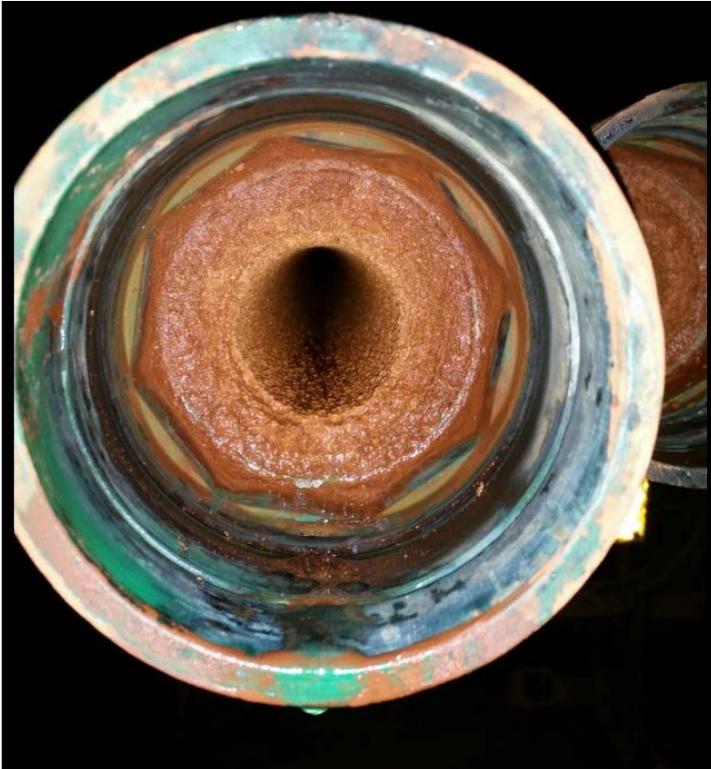


A persistent issue

- Iron bacteria was identified early. Acts to clog abstraction bores, insulate pumps and clog riser and headworks.
- Overall a reduction in pumping efficiency and additional maintenance on materials.
- The bacteria is ubiquitous.
- To date, not much success with management.
- Iron oxide can coat the inside of bulk main pipelines resulting in far greater head loss.
- Iron oxide can develop in ponds and affect downstream infrastructure.

Iron Bacteria/Iron Oxide

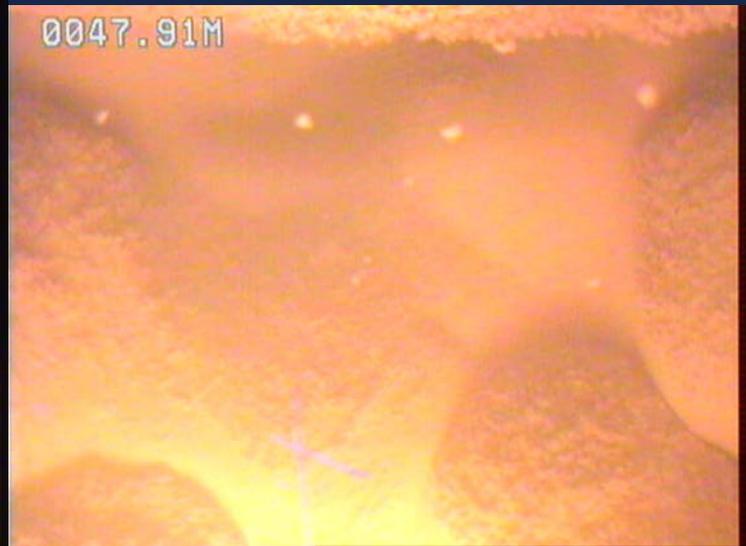
A persistent issue



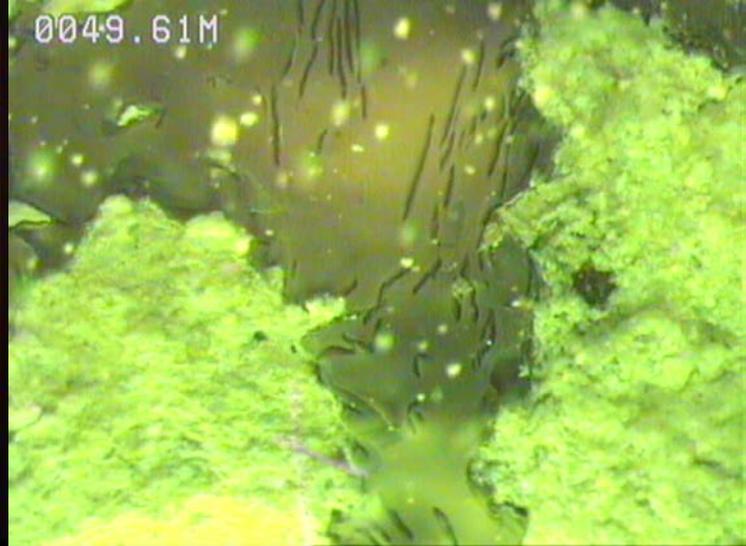
0066.76M



0047.91M



0049.61M



Surprise!

- Early conceptual models neglected the potential for flow from deeper aquifers into the ore zone.
- The Jeerinah formation has relatively low vertical permeability, but much higher horizontal permeability.
- Results in strong upwards gradients when abstracting. This drives saline water ingress and potentially high flows where the confining unit is compromised (ie faults and boreholes).

Award Winning and Regulator Endorsed



“Leading the industry in mine site water management” Department of Water, WA

- 2010 - Winner of **WA Infrastructure innovation**
- 2011 - Winner of the **Australian Water Association**
- 2012 - Winner of **Asia Pacific**
- 2012 - Winner of International Water Association **awards for Innovation**





Fortescue
The New Force in Iron Ore

www.fmgl.com.au

 [@FortescueNews](https://twitter.com/FortescueNews)

jbarclay@fmgl.com.au

Proudly supporting:



GENERATIONone



Our Vision: The safest, lowest cost, most profitable iron ore producer



Safety



Family



Integrity



Determination



Enthusiasm



**Set yourself
stretch targets**



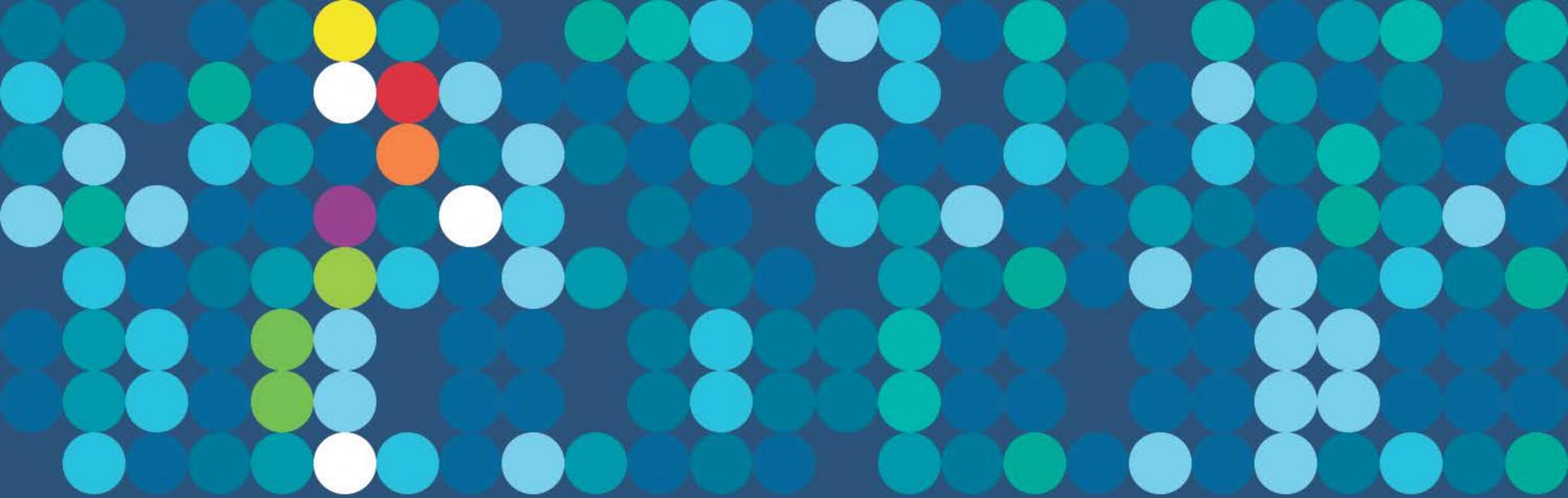
Empowerment



Generating ideas



Frugality



Beenyup – MAR as a Water Resource Management Tool

MAR Essentials - Simon Higginson

simon.higginson@watercorporation.com.au

Fresh  Thinking

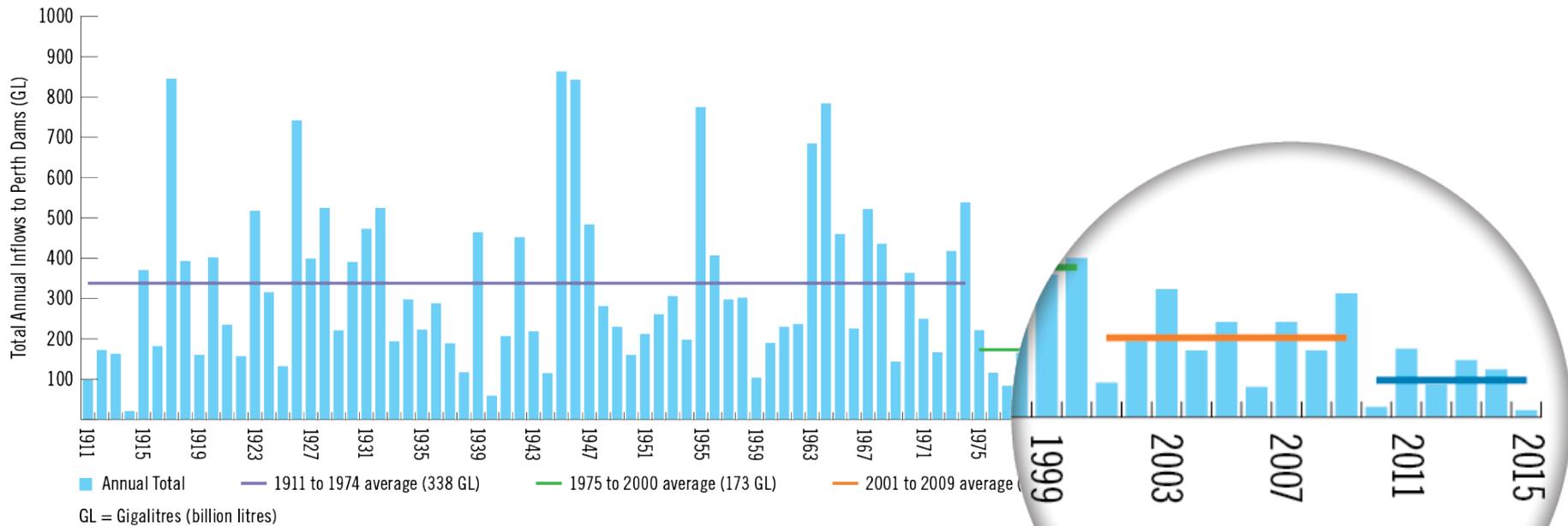
 **WATER**
CORPORATION

Outline

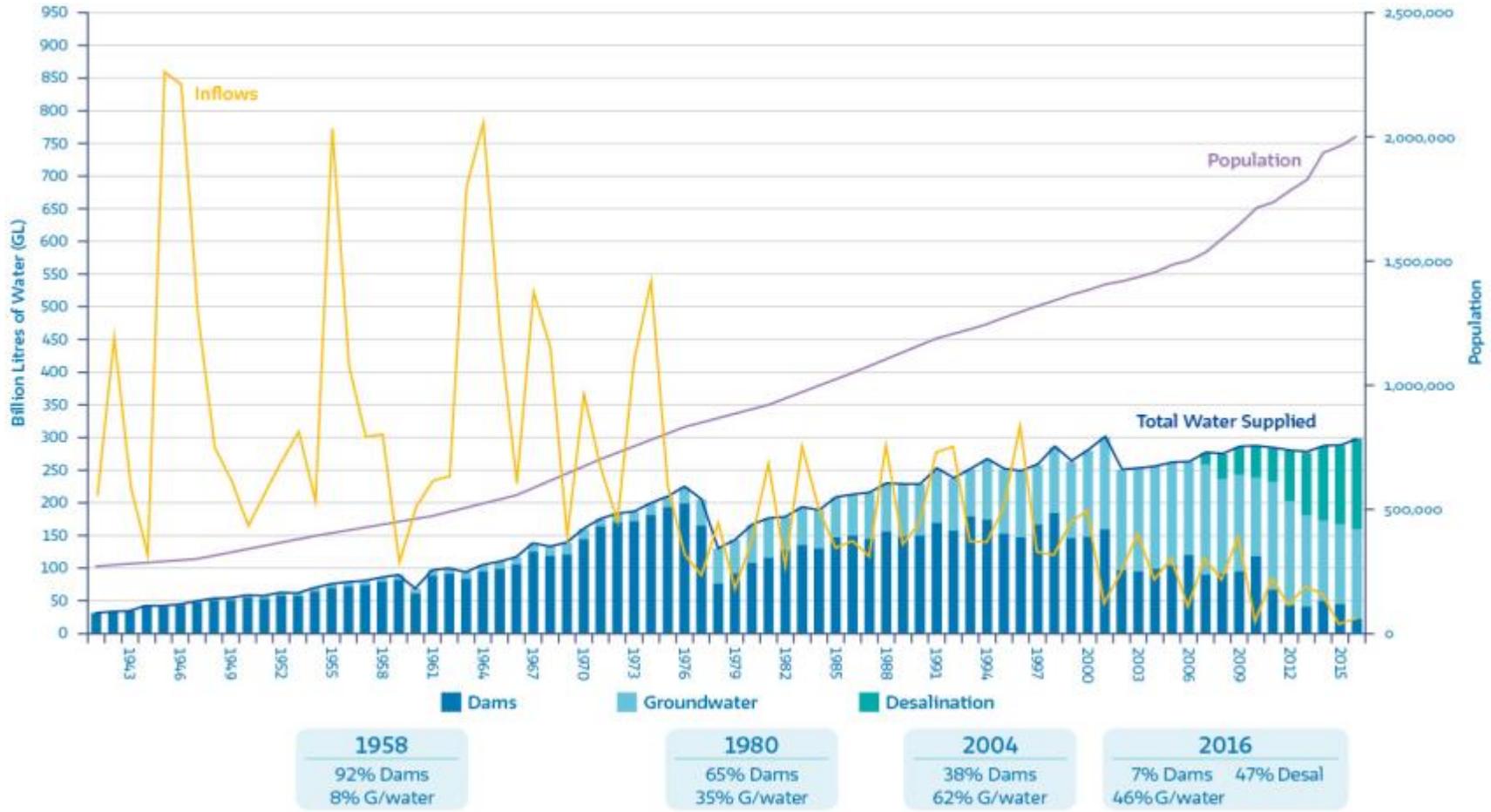


- Background
 - Perth's water supply
 - Why groundwater replenishment (GWR)
- The GWR Trial
- Perth GWR Stage 1
- Perth GWR Stage 2
- Future GWR options

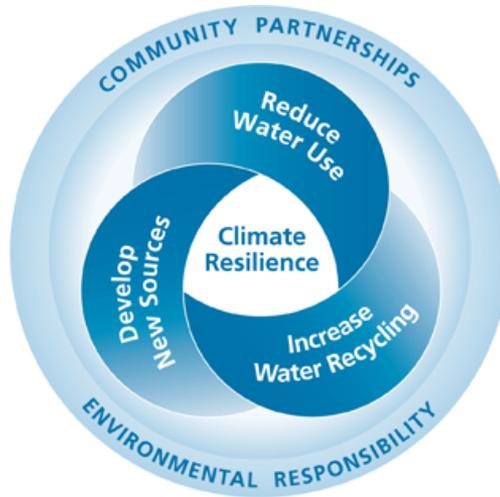
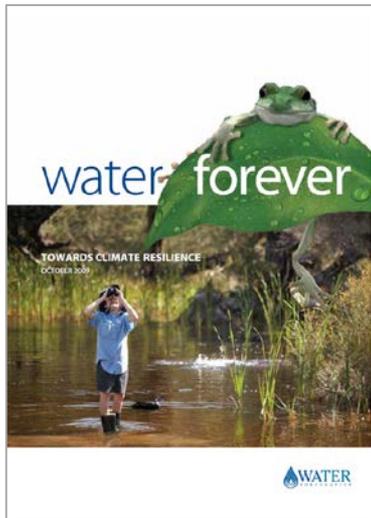
Historical Streamflow into Perth Dams



Historical Streamflow into Perth Dams and Water Supply



Planning Future Sources

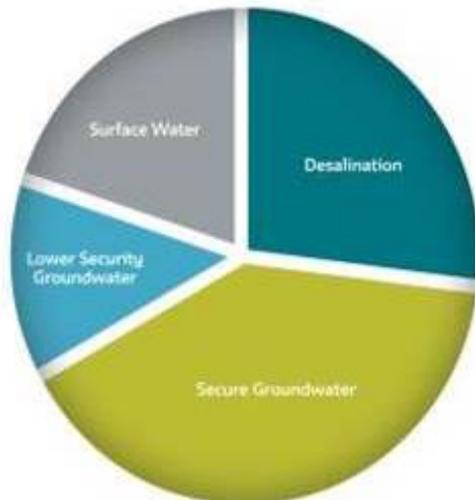


The 50 Year challenge:

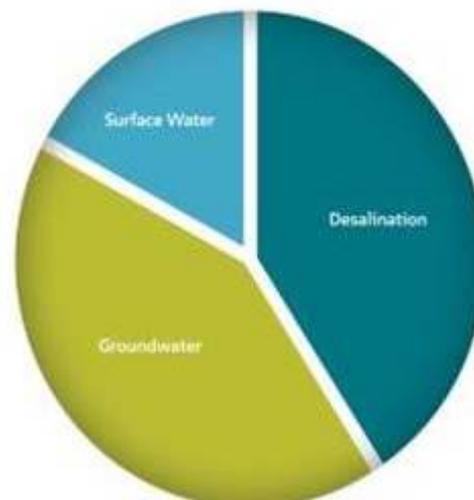
To provide water for all:

- In an even drier climate
- With twice as many people
- With less environmental impact

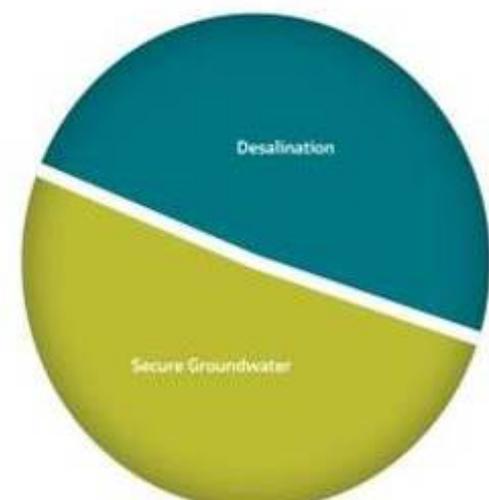
2012



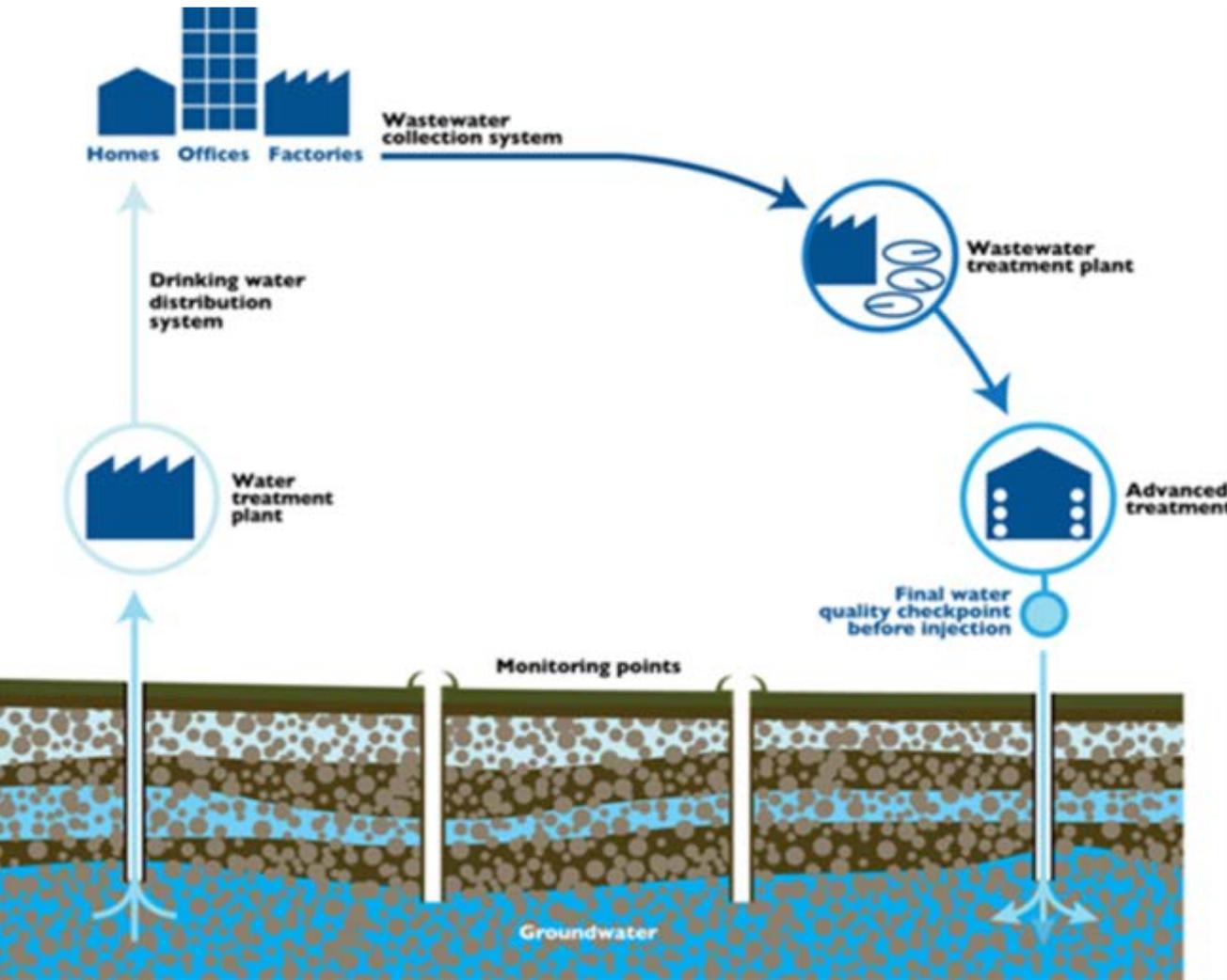
2015



2022



Groundwater Replenishment



- Climate independent source
- Suited to local conditions
- Identified in 2004
- Lack of guideline and regulation
- 2005 – undertake a trial

GWRT Objectives



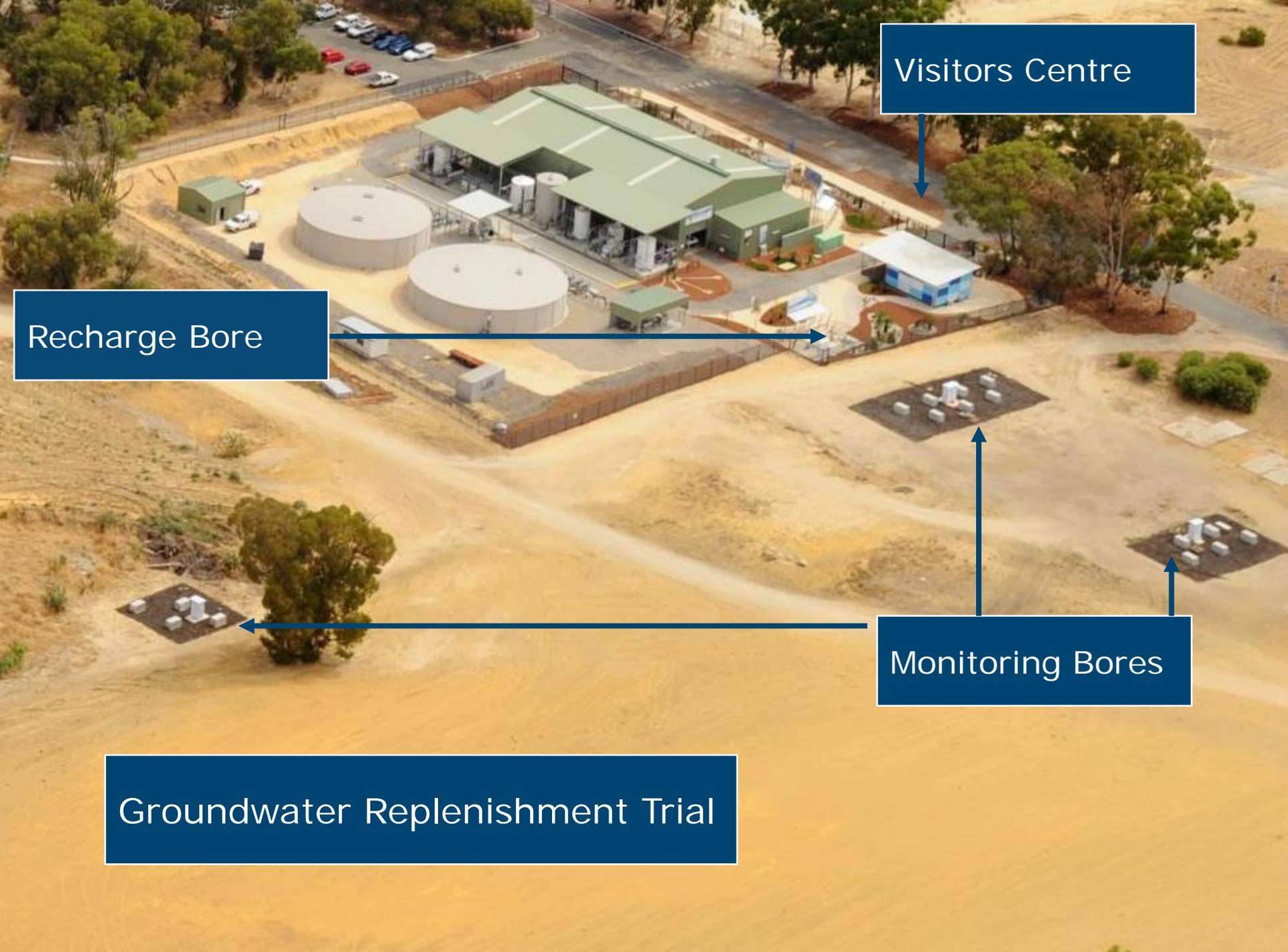
- Technical feasibility
 - Understand the combination of technologies, water quality and flow, human and environmental risks, in partnership with researchers
- Policy and regulation
 - Work with regulators (DoH, DWER – water and environment) to create regulatory frameworks for large GWR schemes
- Community engagement and discussion
 - Allow time for discussion and debate in the community

Visitors Centre

Recharge Bore

Monitoring Bores

Groundwater Replenishment Trial



Advanced Water Treatment



Wastewater Treatment

- Water suitable for ocean discharge

Ultrafiltration – Removes:

- All suspended solids
- Crypto, giardia, bacteria
- Larger virus

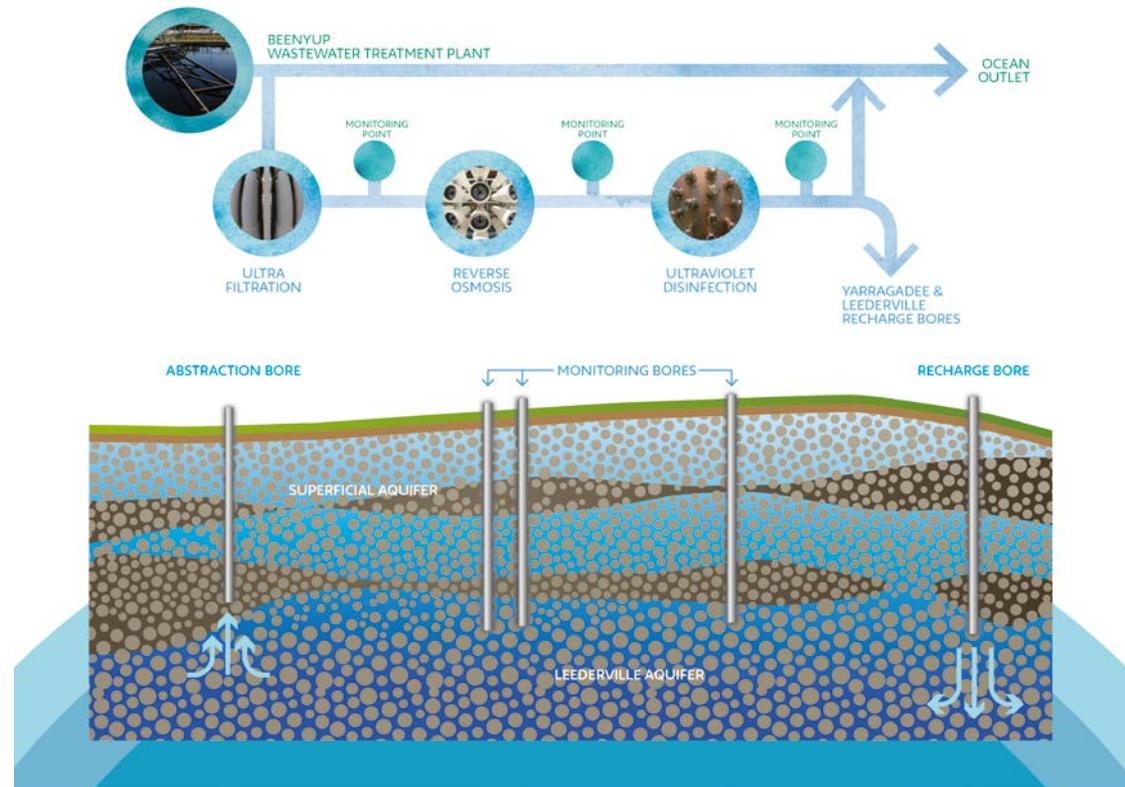
Reverse Osmosis – Removes:

- All virus
- All chemicals larger than a water molecule

Ultraviolet Treatment

- Final disinfection
- Inactivation of bacteria and virus

Water Recycling Process



Groundwater Investigations



Objectives

- Aquifer response – residence times, vertical movement
- EV's protected – water quality changes
- Operational – clogging
- Transferability

Investigations

- Extensive site characterisation
- Regular GW sampling
- Online monitoring: level, conductivity
- Geochemistry & geophysical investigations
- Solute and reactive transport modelling

Research partners

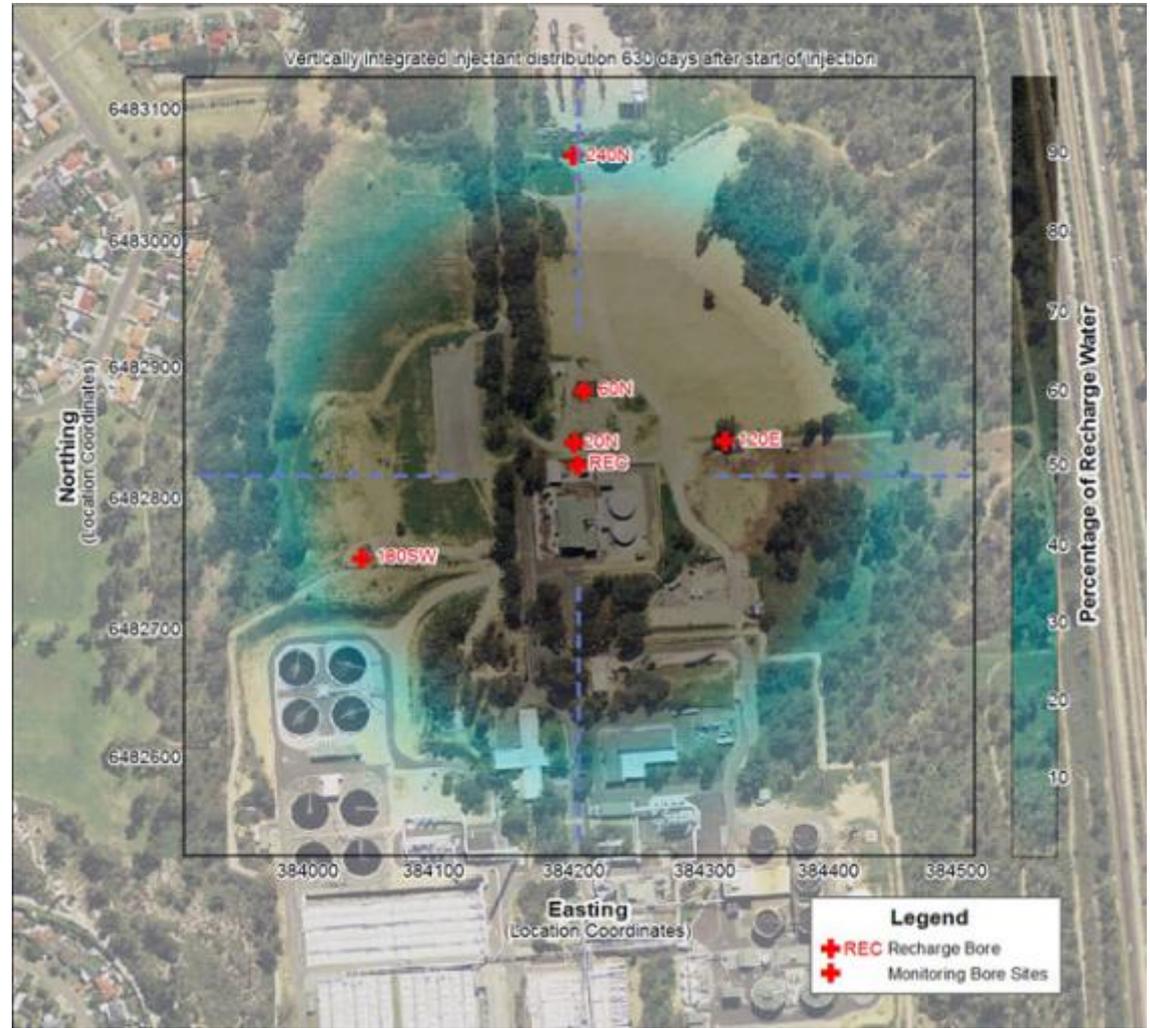
- CSIRO, Curtin Uni, Rockwater, DoW



Recharge during GWRT



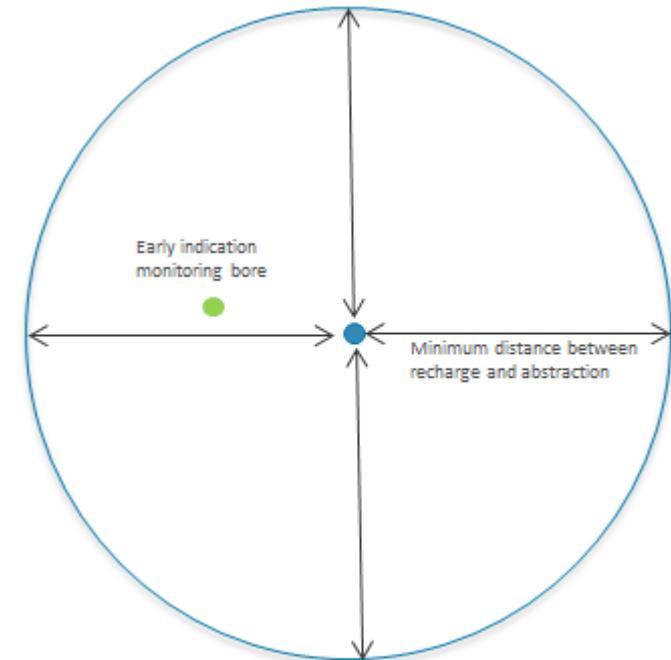
- Recycled water travelled ~250m through the fastest layer during the Trial
- Conductivity used to track breakthrough
- Development of a Recharge Management Zone



Monitoring and Management of RMZ



- Monitoring
 - Early indication - monitor between 50-100m from the point of recharge
 - If necessary implement a management response (additional monitoring, research, additional or altering AWRP treatment processes)
 - If required, drill additional monitoring bores
- Management
 - DoH – manage within WWS/GWR MoU
 - DER – may require on-going groundwater quality monitoring within RMZ as part of licence conditions
 - DoW - appropriate for DoH to manage via WWS/GWR MoU



Aquifer Response



- Water Quality
 - Buffer pyrite oxidation
 - Limited pH declines
 - Limit metal mobilisation
- Pressure
 - Limited potential for movement into Superficial aquifer
- Clogging
 - High water quality
 - Down hole valve
 - Bore development
 - Monitoring

Technical Feasibility



- Produced 2.55GL of recycled water
- 4,100 recycled water samples – 100% compliance
- 58,200 groundwater samples – 100% compliance
- Process operated within spec for more than 99.99% of the time



Policy and Regulation



- Regulatory framework in place
- Iterative risk assessment process based on MAR guidelines
- Define Recharge Management Zone
- Defined water quality guidelines
- 1:1 allocation for GWR
- All regulators (DoH, DoW, DER) supported recommendation to expand



Community Support



- Over 7,400 visitors
- Maintained bi-partisan political support
- Average 72% community support
- Increase from 70% to >90% support after tours
- Announcement of expansion with positive media and community action
- No community outrage, even following occasional negative media coverage



Full Scale GWR – 7GL/yr



- August 2013 GWR endorsed and next water source

Minister's Press Release

- Recycling scheme to help secure Perth's water supply
- Initiative will supply 7 billion litres of water every year
- Landmark three-year trial proves resounding success
- All 62,300 water quality samples met strict health and environmental guidelines



GWR Stage 1 morphs to 14GL/yr



- July 2014 State Cabinet approved Perth GWR Stage 1 as 14GL/yr
- All recharge to be undertaken on site
 - 3 Leederville wells
 - 1 Yarragadee well
- Construction launch October 2014
- Recharge to commence 2017







.. And then 28GL/yr



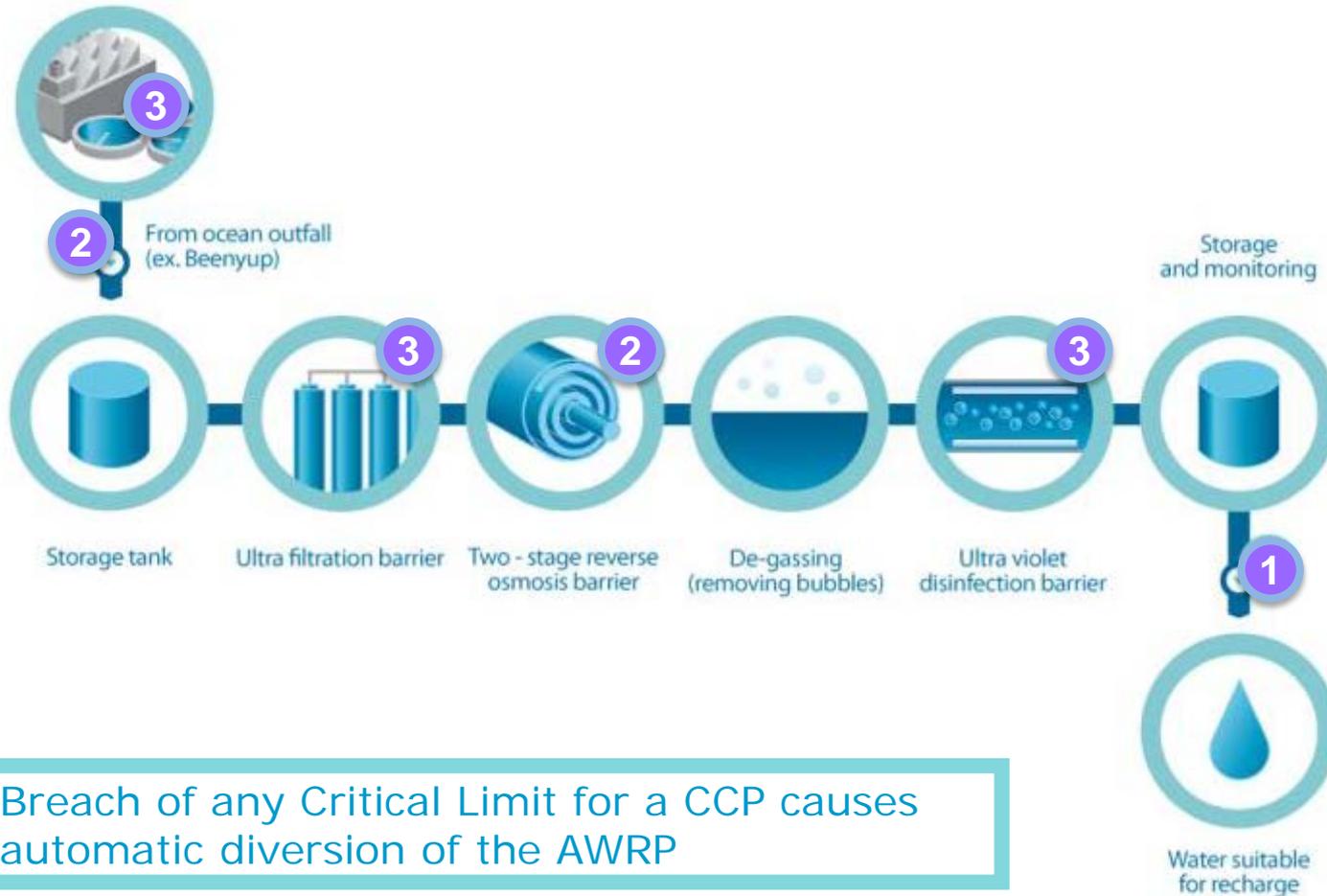
- “We always planned to double the plant's capacity and we have made the sensible decision to start that process now”
- The Corporation will invest \$232 million to expand the scheme to recharge up to 28 billion litres of water a year, which includes duplication of the recycling plant at Craigie and new recharge bores”



Perth GWR Scheme – Stage 2



AWRP – Critical Control Points



 Critical Control Points

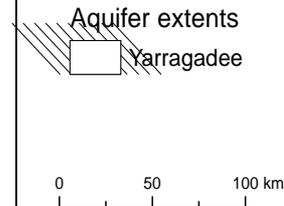
Total AWRP Critical Control Points = 11

What are the recharge options?



Yarragadee Aquifer

- The deepest of the aquifers that the Water Corporation uses
- Water Corporation is essentially the only user
- Large volumes of water is stored
- Very old water
- Variable quality – TDS and temperature



*Aquifer data supplied
by Department of Water*

Leederville Aquifer

- A limited number of users
- Large volume of water is stored
- Old water
- Recharge from the Superficial aquifer
- Direct effects on wetlands is reduced

Aquifer extents

 Leederville

0 50 100 km



*Aquifer data supplied
by Department of Water*

Confined aquifers

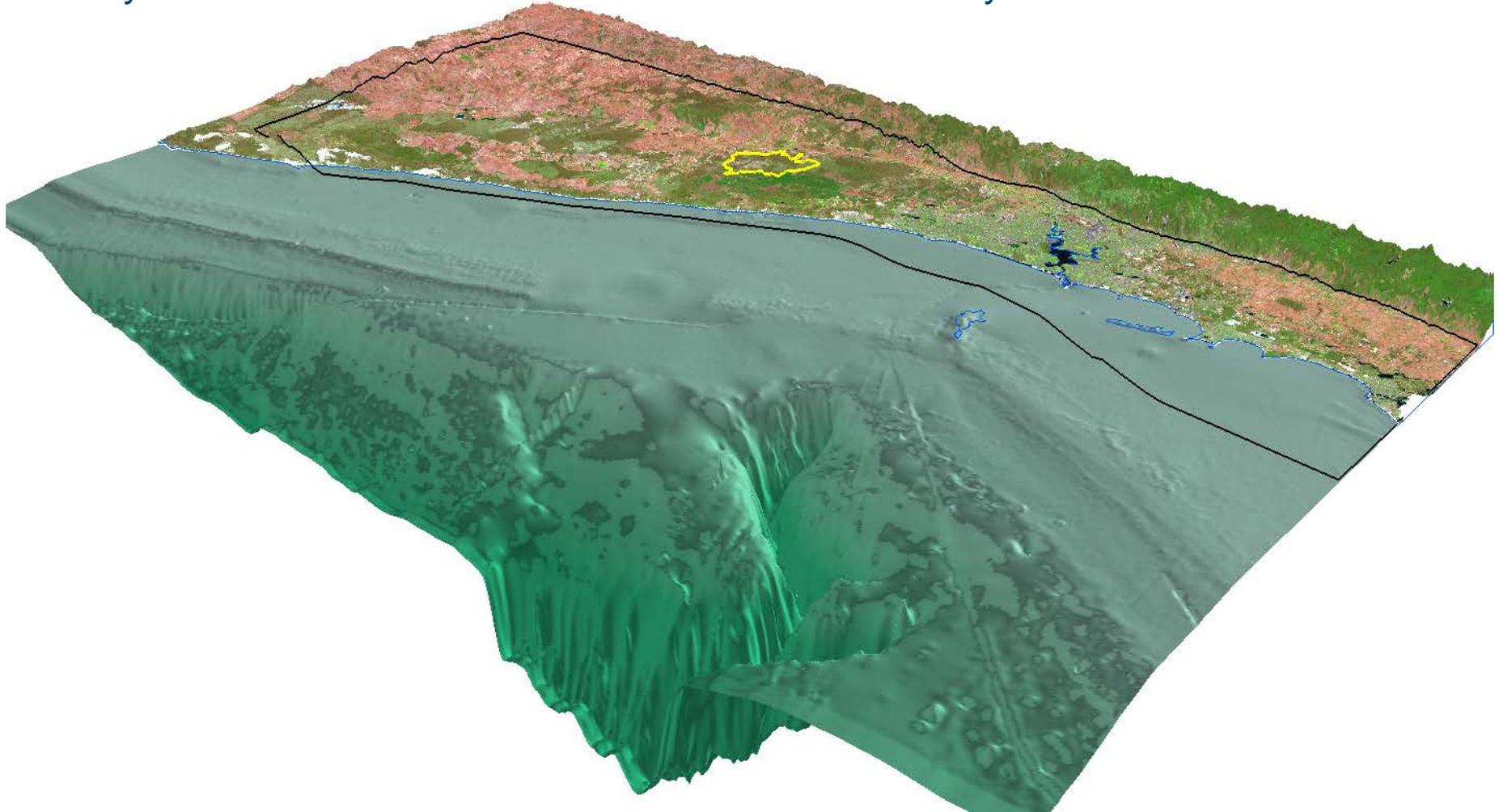


Leederville offshore

- 20,000GL
- 400 years at current abstraction

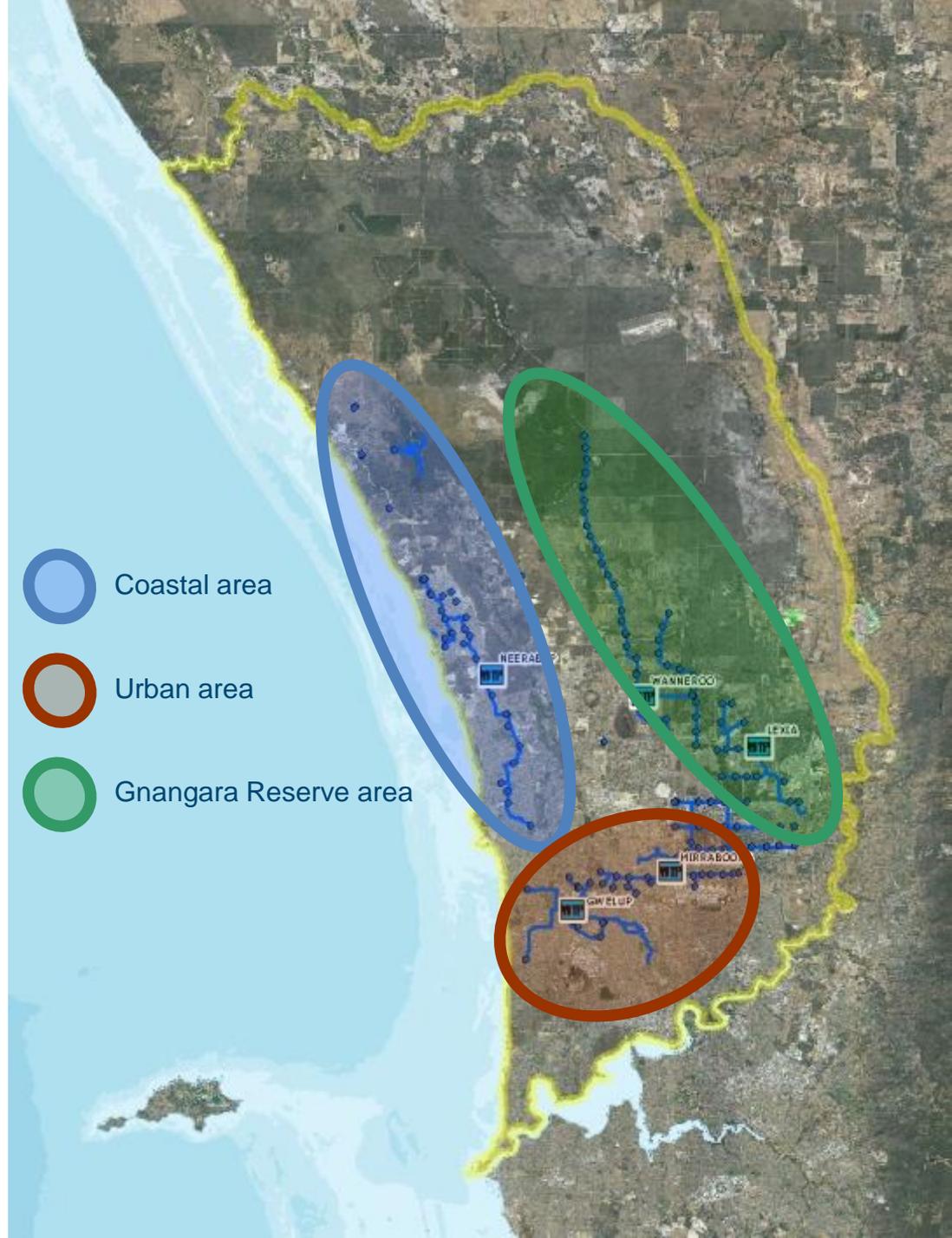
Yarragadee offshore

- 50,000GL
- 1000 years at current abstraction

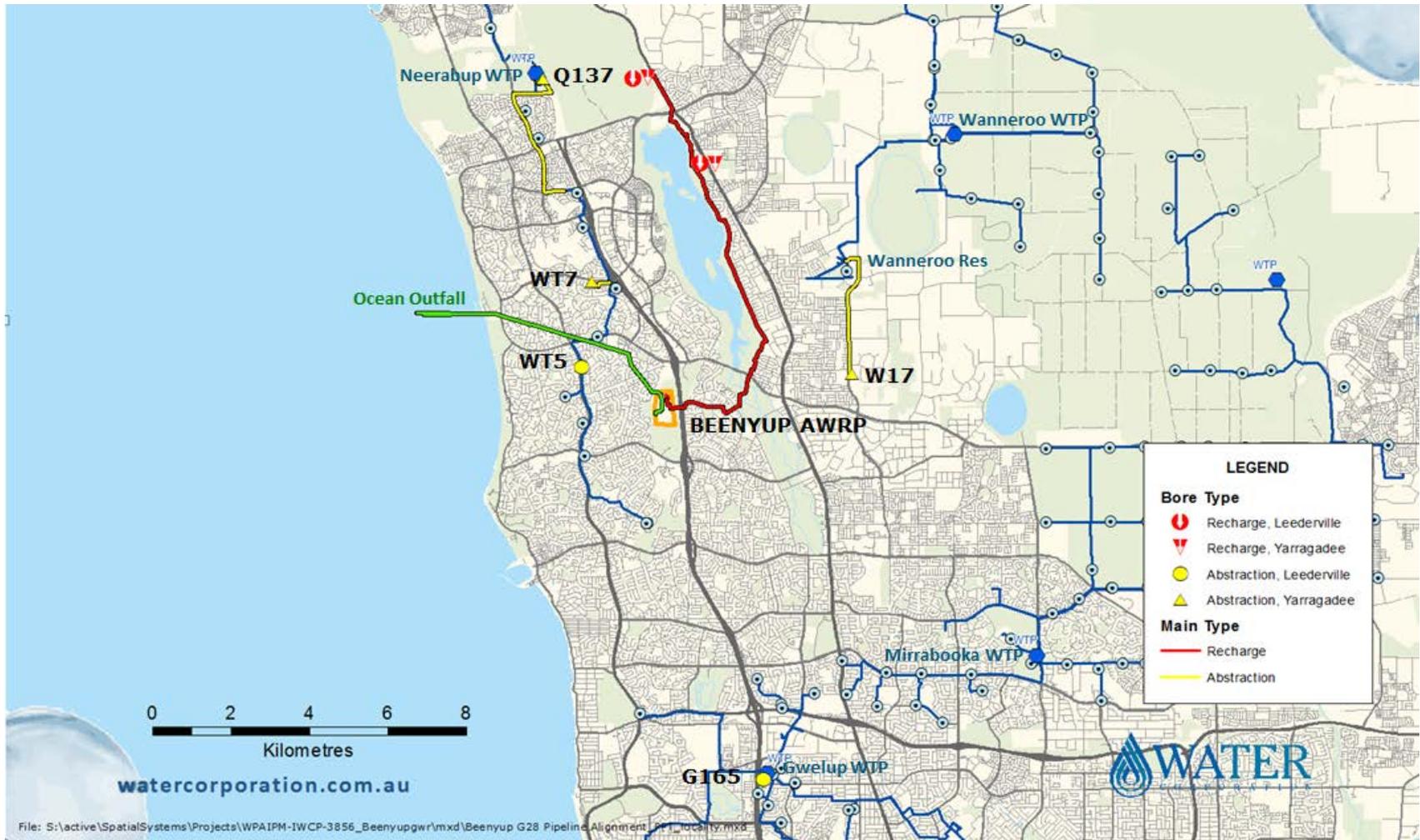


Superficial Aquifer

- Shallowest of the aquifers
- Many users (private and public)
- Direct recharge
- Connects with wetlands
- Higher risk of contamination from human activities

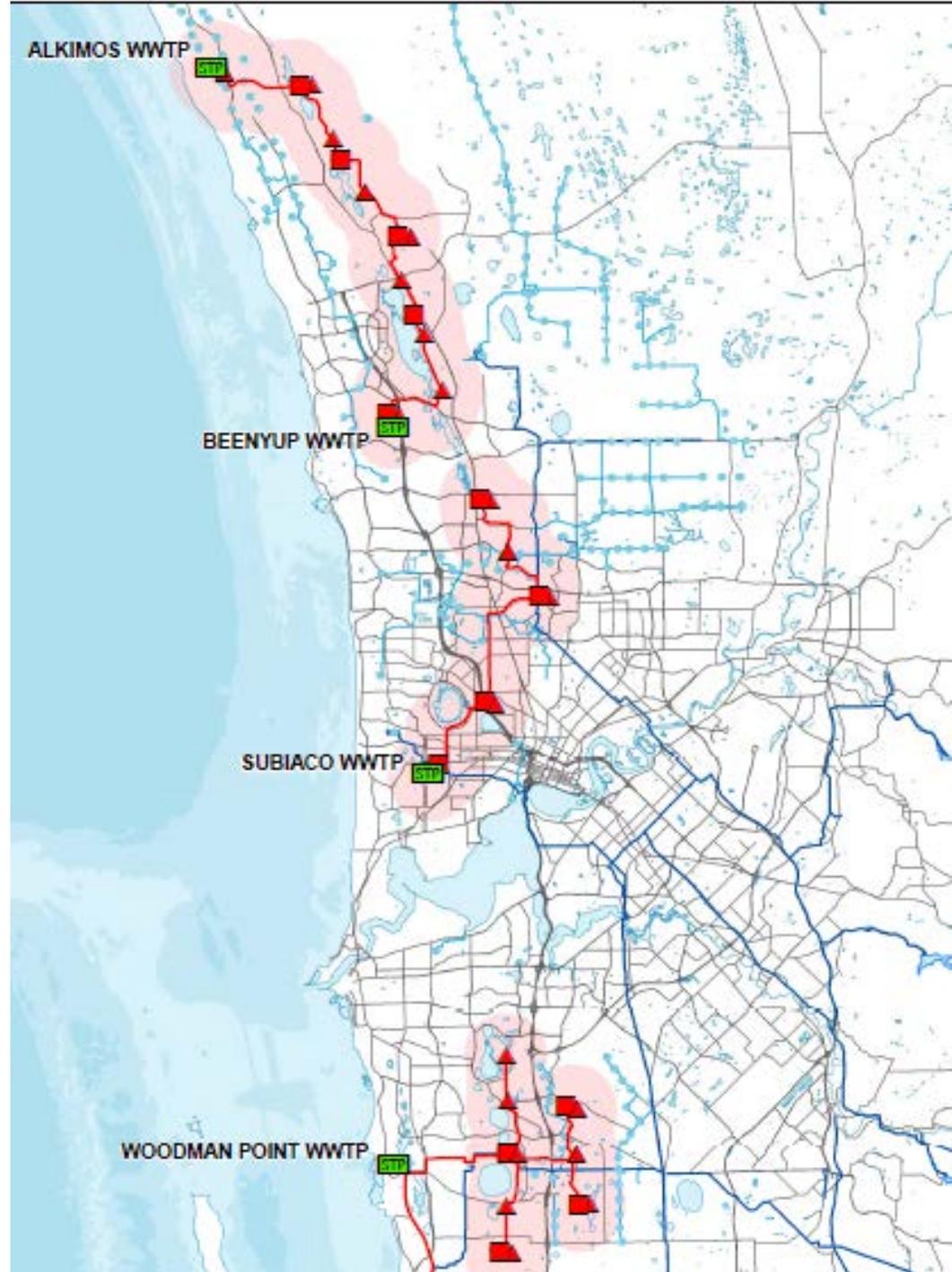


Stage 2 GWR - Recharge



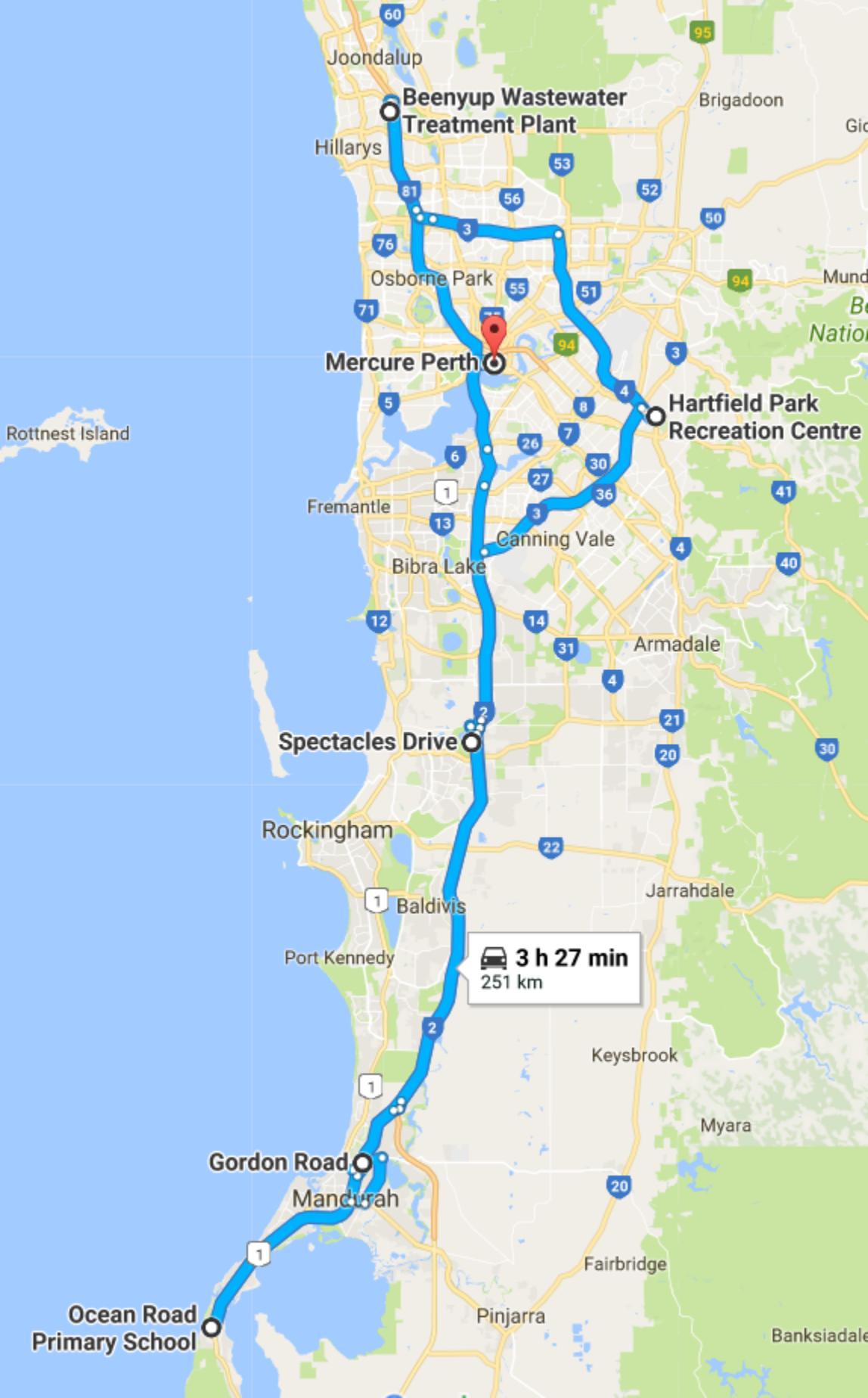
Future GWR

- Maximise GWR from northern metro WWTP – up to 70 GL/yr
 - Beenyup – 35GL
 - Subiaco – 20GL
 - Alkimos – 15GL
- Up to 50 GL/yr from Woodman Point
- Total 120GL/yr
- Current demand ~300GL/yr



Questions??





Beenyup Wastewater Treatment Plant

Mercure Perth

Hartfield Park Recreation Centre

Spectacles Drive

Gordon Road

Ocean Road Primary School

 3 h 27 min
251 km

Case study: recharge of potable and tertiary-treated wastewater into a deep, confined sandstone aquifer in Perth, Western Australia.

Karen Johnston: Rockwater Pty Ltd

Michael Martin and Simon Higginson: Water Corporation Western Australia

Abstract

The Water Corporation of Western Australia started investigating the feasibility of recharging potable water into the deep, confined aquifers beneath the Perth Metropolitan area, Western Australia, in 2000. Managed aquifer recharge (MAR) was identified as a potentially significant operating strategy for the Integrated Water Supply Scheme with possible benefits to the environment and providing drought security, improved groundwater quality, groundwater banking and maintenance of groundwater levels.

Perth is largely dependent on groundwater for its municipal water supply, with up to 50% of the total supply sourced from the vast groundwater system that underlies the region. The Perth groundwater system is part of the Perth Basin, and is bounded in the east by crystalline rocks of the Yilgarn Craton and extends many kilometres off shore to the west. The onshore portion of the aquifer stretches 250 km along the coast in a narrow strip of clastic sediments that are more than 2,000 m deep. The sediments have been laid down under varying depositional environments over millions of years. The groundwater system can be broadly divided into three main aquifers: the shallow, unconfined superficial aquifer, and the deep, confined Leederville and Yarragadee aquifers. The Leederville aquifer has been the target aquifer for MAR to date, and there are plans to incorporate the deeper Yarragadee aquifer into future groundwater replenishment operations.

The Leederville aquifer is a major confined aquifer that is typically between 150 and 400 m thick. It is subdivided into three members:

-) The Pinjar Member comprises mainly thin sandstone beds interlayered with siltstone and shale. It generally acts as an aquitard and conformably overlies the Wanneroo Member;
-) Individual sandstone beds of the Wanneroo Member are about 10 to 20 m thick, with interlayered siltstone and shale beds of varying thickness. The sandstone beds are weakly consolidated and composed predominantly of coarse-grained, poorly-sorted quartz. The aquifer transmissivity is in the order of 500 to 2,000 m³/d/m, and groundwater salinity is generally between 250 and 1,000 mg/L TDS. The Wanneroo Member is the target zone for aquifer recharge and conformably overlies the Mariginiup Member;
-) The Mariginiup Member consists of thinly interbedded siltstone and shale with few very thin sandstone beds. It acts as a confining layer.

Investigations commenced with the establishment of a small aquifer storage and recovery (ASR) trial at Jandakot, injecting potable surface water into an existing production bore. The preliminary trial was successful, with clogging managed by backwash-pumping techniques. This facility was upgraded to a pilot scale operation with a new recharge bore and associated infrastructure. Having demonstrated the technical feasibility of ASR in the Leederville aquifer, a large scale ASR site was established at Mirrabooka, where potable treated-groundwater was recharged to the aquifer at rates up to 7 ML/d. Clogging was similarly managed using backwash-pumping techniques. The ASR trials ultimately led to the establishment of a state of the art Groundwater Replenishment Scheme at the Beenyup wastewater treatment plant in Craigie, where ultra-purified wastewater is currently being recharged to the Leederville aquifer for future re-use in the IWSS. This case study presents results from these investigations with particular regard to the degree and type of clogging encountered using different water types at each site and the operational management of clogging.

Introduction

The Water Corporation is the water service provider to the capital city of Perth in Western Australia. Perth is largely dependent on groundwater for its municipal water supply, with up to 50% of the total supply sourced from the extensive groundwater system that underlies the region. While the groundwater resources are vast, there has been significant drawdown in the major aquifers over the last twenty years or more, and the Water Corporation has been investigating the feasibility of recharging potable and reclaimed water into the deep, confined aquifers lying beneath the metropolitan area, since 2000.

Managed aquifer recharge (MAR) was identified as a potentially significant operating strategy for the Integrated Water Supply Scheme (IWSS) with possible benefits to the environment, for example maintaining groundwater levels in areas with groundwater dependent ecosystems and preventing saline water intrusion into the aquifers. It also provides drought security, improves groundwater quality in areas of marginal salinity, facilitates groundwater banking, and, with the use of reclaimed water, increases the amount of water available for drinking-water supplies, as the Water Corporation seeks to identify additional water resources under drying climatic conditions.

This paper briefly reviews the three MAR schemes developed to investigate the feasibility of implementing aquifer recharge technology under local conditions: from a small-scale pilot aquifer storage and recovery (ASR) project at Jandakot, through a large-scale research and development ASR project at Mirrabooka, to a fully operational groundwater replenishment scheme (GWRS) at Beenyup. Figure 1 shows the site locations. The focus of the discussion in this case study will be the degree and type of clogging encountered at each site and how this has been successfully managed.

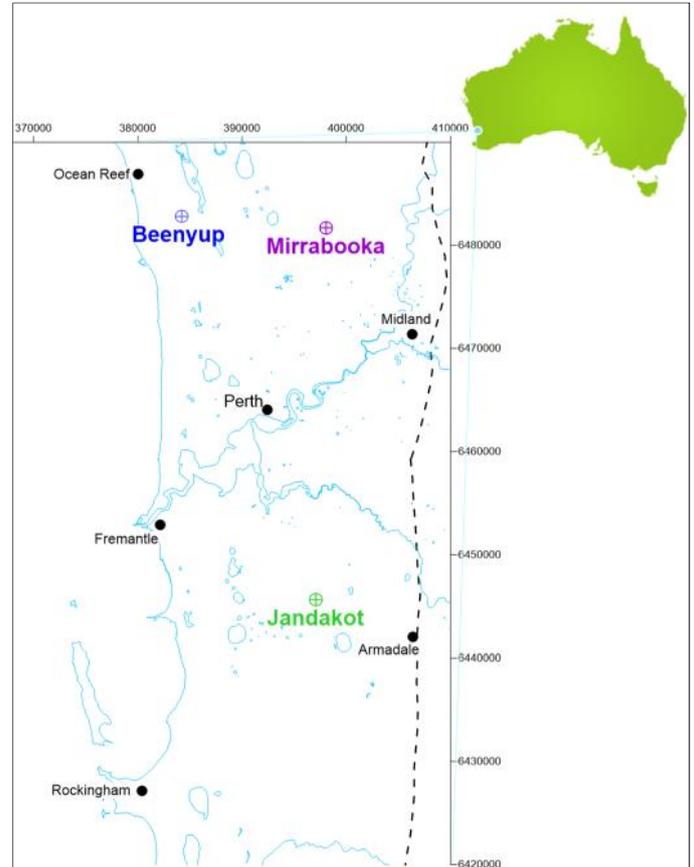


Figure 1: Site Locations

Hydrogeological Background

The Perth groundwater system lies within the Perth Basin. It has been extensively explored and the results have been detailed and summarised in Davidson (1995) and updated in Davidson and Yu (2008). The Perth groundwater system is bounded to the east by crystalline rocks of the Yilgarn Craton, as marked by the Darling Scarp, and extends many kilometres off shore to the west. The onshore portion of the aquifer system stretches 250 km along the coast in a narrow strip of predominantly siliciclastic sediments that reach more than 2,000 m depth. The sediments have been laid down under various environmental conditions over millions of years. The groundwater system can be broadly divided into three main aquifers: the shallow, unconfined superficial aquifer, and the deep, confined Leederville and Yarragadee aquifers. The Leederville aquifer has been the target aquifer for MAR to date, and will be the focus of the discussion herein, although there are plans to incorporate the deeper Yarragadee aquifer in future groundwater replenishment operations. Figure 2 shows a typical site-scale aquifer profile for these operations.

Information regarding the Leederville aquifer has been taken from the above references and has been supplemented with site-specific data and recent work by Leyland (2011).

The Leederville Formation is typically between 150 and 400 m thick in the Perth region and was deposited during the Early Cretaceous period under marine and non-marine conditions. It is subdivided into three members, the Pinjar Member, the Wanneroo Member and the Mariginiup Member, all of which are present at the sites under consideration.

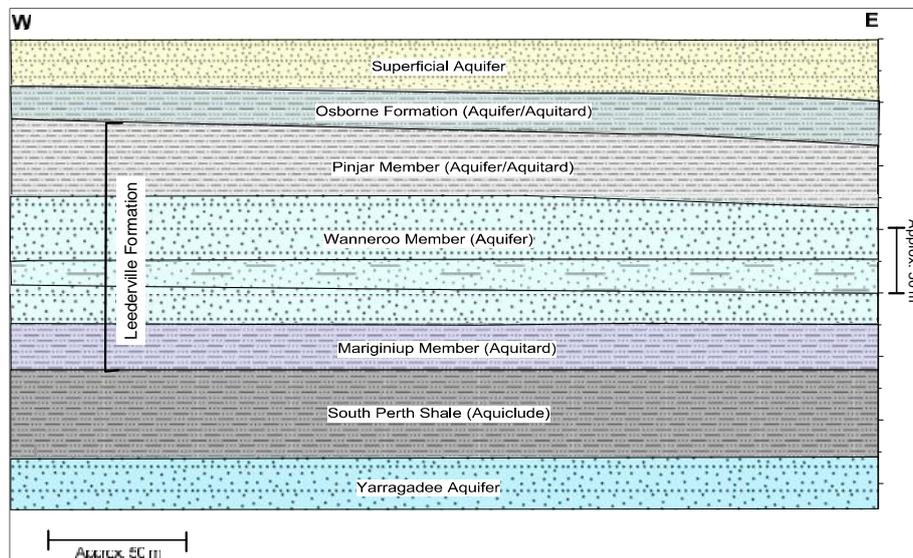


Figure 2: Schematic cross section showing typical aquifer profile for the Perth MAR sites

The Pinjar Member unconformably underlies the Osborne Formation and comprises mainly thin beds (<6 m) of fine- to coarse-grained, poorly sorted and commonly silty sandstone, interlayered with dark grey to black siltstone and shale. It generally acts as an aquitard and conformably overlies the Wanneroo Member.

The Wanneroo Member is the target zone for recharge via injection and comprises weakly consolidated, predominantly coarse-grained but poorly sorted, subarkose sandstone beds, about 4 to 20 m thick with interlayered siltstone and shale beds of varying thickness. The depositional environment has been determined to be predominantly fluvial in the north, with periods of low energy tidal inundation and sedimentation. At the subject sites, the aquifer transmissivity for the screened sandstone beds ranges from about 650 m³/d/m at Mirrabooka to 2,100 m³/d/m at Beenyup. Groundwater salinity varies from site to site, with depth in the aquifer, and with aquifer lithology; it is generally between 250 mg/L TDS near recharge areas and in the coarse-sandstone beds with higher permeability, and 1,000 mg/L TDS within the siltstone and shales and in areas of marine deposition or inundation. Table 1 provides a summary of the background hydrogeological data for the receiving aquifer at each site. The Wanneroo Member conformably overlies the Mariginiup Member.

Table 1: Hydrogeological data for the receiving aquifer at Perth Metropolitan MAR sites

Site	Total Bore Depth	Screened Intervals	Length of Screens	Static Water Level	Static Water Level	Bore Yield	Transmissivity	Hydraulic Conductivity	Groundwater Salinity
	(m bgl)	(m bgl)	(m)	(m bgl)	(m AHD)	(kL/day)	(m ² /day)	(m/day)	(mg/L TDS)
Jandakot	228	178-217	39	30	0	6,030	790	20.3	520-1,550
Mirrabooka	434	320-368 394-427	81	43.5	2.5	7,780	650	8.0	520-1,400
Beenyup	236	122-224	102	27.6	-6.9	8,640	2,100	20.3	450-1,100

The Mariginiup Member represents a prograding succession of tidal bars and consists of thinly interbedded siltstone and shale with few, very thin sandstone beds. It acts as a confining layer and conformably overlies the South Perth Shale.

Provenance analysis using major and trace elements suggests local granitoids from the Yilgarn Craton have been the principal contributor of sediment to the Leederville Formation in the Perth area (Prommer, et. al., 2011). The predominant minerals in the aquifer matrix are quartz and K-feldspar, with kaolinite making up the bulk of the clay fraction. Accessory minerals include Na-feldspar, muscovite, pyrite, siderite, chlorite and crandalite. Groundwater quality and mineralogical data from Jandakot also indicates the presence of calcite at this site, which along with the

higher background salinity values, suggests the Wanneroo Member was deposited under marine conditions, or experienced a period of marine inundation at this location.

Background Groundwater and Recharge Water Quality

Groundwater in the Leederville aquifer at the three MAR sites tends to be fresh to slightly brackish, circumneutral to slightly acidic at Mirrabooka and Beenyup to slightly alkaline at Jandakot, and of a sodium-chloride type (Figure 3). In the recharge zone the groundwater is anoxic and reducing conditions prevail. The groundwater in the Leederville

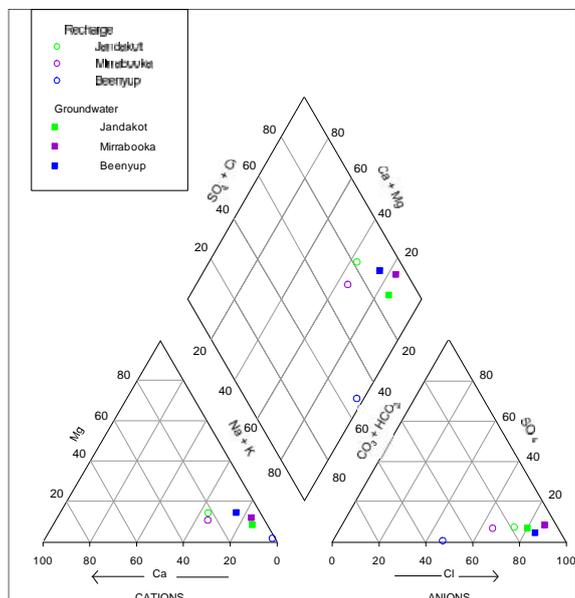


Figure 3: Average water composition for Leederville MAR sites and recharge waters

aquifer tends to be naturally high in turbidity, and generally has elevated levels of iron and manganese, which are routinely removed during standard water treatment processes in the IWSS.

The recharge water at each site varies, from potable mains water sourced from hills dams at Jandakot and treated groundwater at Mirrabooka, to highly-treated reclaimed wastewater at Beenyup. The geochemical composition of the recharge water for each project is plotted in Figure 3, and average values for key water quality parameters related to clogging are presented in Table 2. The water recharged at all sites is of a very high quality for injection.

At Jandakot, water was diverted from the Serpentine Main, which distributes water from the Serpentine and other dams in the Perth Hills to the southern metropolitan area. The water is fresh (<200 mg/L TDS), slightly acidic and of a sodium-chloride type. The total suspended solids (TSS) are < 5mg/L and turbidity is generally below 1 NTU. Nitrate and dissolved organic carbon (DOC) are very low (<0.2 mg/L and <2.0 mg/L, respectively). Compared to the other sites, total iron and manganese levels are slightly elevated (about 0.1 mg/L and 0.01 mg/L, respectively), and it is believed that this may contribute to the higher modified fouling index (MFI) results (average 70 s/L²). Particle size distribution (PSD) analysis indicated 100% of all suspended particles were less than 50µm in diameter, 99% were smaller than 10µm in diameter and about 50% were smaller than 2µm in diameter.

Table 2: Recharge water quality parameters related to clogging

Site	Total Dissolved Solids		Organic Carbon		Nitrate		Total Iron		Total Manganese		Total Suspended Solids		Turbidity		Particle Size Distribution			Modified Fouling Index		
	Ave.	Max.	Ave.	Max.	Ave.	Max.	Ave.	Max.	Ave.	Max.	Ave.	Max.	Ave.	Max.	50 µm	10 µm	2 µm	Ave.	Max.	
	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(NTU)	(NTU)	(% <)	(% <)	(% <)	(s/L ²)
Jandakot	154 (39)	250	<2 (31)	4.9	<0.2 (22)	2.1	<0.1 (37)	0.24	<0.011 (8)	0.05	<4.2 (39)	5.0	<0.8 ¹ (26)	11	100 (6)	99 (6)	52 (6)	70 (26)	149.3	
Mirrabooka	454 (22)	515	<2.1 (22)	8.4	<0.9 (16)	2.0	<0.02 (24)	0.08	<0.003 (24)	0.008	<5.0 (14)	5.0	<0.3 (24)	1.3	Insufficient particles to measure (1)			8 ² (4)	13.7	
Beenyup	31 (33)	50	<1 (29)	<1	2.1 (34)	3.6	<0.01 (34)	0.01	<0.001 (34)	<0.001	<1.1 (34)	4.0	<0.5 (34)	0.5	NA	NA	NA	NA	NA	

1. Average calculated without outlier of 11 mg/L

2. Average calculated from available raw data - it has been reported elsewhere as 3 s/L² (e.g. Prommer et al)

Numbers in parenthesis indicate number of samples and < indicates values calculated using limit of reporting (LOR) for analysis where values were below LOR

At Mirrabooka, water was diverted from the Gngangara Rd distribution main, which distributes water from the Wanneroo Reservoir to the northern metropolitan area. The reservoir is supplied from nearby groundwater treatment plants, which source water from the superficial and confined aquifer systems. The water is fresh (<500 mg/L TDS), slightly alkaline and of a sodium-chloride type. Total suspended solids are mostly below 5 mg/L and turbidity is generally very low, <0.3 NTU. Nitrate and DOC are also very low (<0.2 mg/L and <2.0 mg/L, respectively) as are total iron and manganese (about 0.02 mg/L and 0.003 mg/L, respectively). The MFI was measured for a few samples during the first injection cycle, and gave very low values – in the order of 5 s/L². The one sample analysed for PSD yielded no results due to insufficient particles.

At Beenyup, highly treated recycled water from the Beenyup Advanced Water Recycling Plant (AWRP) is used to recharge the aquifer. The AWRP further treats secondary-treated wastewater through ultra-filtration, reverse osmosis and ultra-violet disinfection to meet the Australian guidelines for drinking water and water recycling, in addition to other site specific guidelines. The water has a very low ionic strength (<50 mg/L TDS), it is slightly alkaline and of a sodium-bicarbonate type (Figure 3). Total suspended solids and turbidity are very low, generally <1 mg/L and <0.5 NTU, respectively. Nitrate levels are elevated compared to the other sites (generally about 2 mg/L), but DOC is very low, <1.0 mg/L. Total iron and manganese are generally below the limits of reporting (0.01 mg/L and 0.001 mg/L, respectively). No samples have been analysed for MFI or PSD as the treatment process effectively removes all solid particles (Water Corporation, 2012).

Site Set-up

Water is recharged to the Leederville aquifer at each site via an injection bore. At Jandakot and Mirrabooka the bore was also used for production, at Beenyup the bore is used for injection alone.

At each site, the injection bore was drilled using mud-rotary drilling techniques and was constructed using large-diameter, reinforced-fibreglass blank casing to the top of the aquifer, cement-grouted to the surface. Stainless steel riser pipe and screens were telescoped through the aquifer interval and held in place by an inflatable packer. Screen aperture is mainly 0.5 mm. At Jandakot and Beenyup, the aquifer annulus was filled with graded gravel. The annulus was left open at Mirrabooka with the aim of developing a natural gravel pack. This variation in construction was intended to inform future decisions regarding preferred injection bore construction with regard to bore clogging performance and was in response to several studies (e.g. Segalen et al, 2005 and Gerges, 1999) that suggest screens with open hole and/or natural gravel pack may be more efficient for ASR. The bores were developed using standard air-lift and jetting techniques.

A filtration system was installed at Jandakot and Mirrabooka to filter the recharge water to 50 μ m prior to injection to minimise the amount of suspended solids introduced to the aquifer, and in particular to minimise the risk of clogging due to a “slug” of poor quality water, should one occur.

A purpose-designed pump was installed in the bores at Jandakot and Mirrabooka to provide automated backwashing capabilities for the management of clogging. The pumps are designed to enable injection at controlled flow rates through an automated down-hole flow valve located above the pump unit. The valve is closed when the pump operates for backwashing or production. The valve is also utilised to implement “surge-backwashing” during the recovery phase, where the down-hole valve is opened during pumping to allow pumped water to recirculate through the valve. The pump is then stopped and the water in the pump column flows back into the bore casing producing a surging action. Finally, the pump is started again and the backwash water removed from the bore.

Monitoring bores were drilled and constructed at each site between 15 and 240 m from the injection bore. There are two monitoring bores at Jandakot (15 m and 60 m), five monitoring bores at Mirrabooka (two at 15 m and three at 40 m) and twenty-two monitoring bores at Beenyup (seven at 20m, five at 60 m, four at 120 m, three at 180 m and three at 240 m). At Mirrabooka and Beenyup the multiple bores at each site are screened at various depth intervals to capture information from discreet aquifer zones.

On-line monitoring equipment was installed at the injection bores to monitor flow rates and water quality parameters: salinity, temperature and turbidity. At Beenyup, pH and oxygen reduction potential (ORP) were also measured online. Down-hole pressure transducers were installed in each of the injection and monitoring bores to provide continuous water-level response data.

Operational Summary for Each Trial

The main operating parameters for each site are summarised in Table 3.

Table 3: Operational summary for the Perth Metropolitan MAR trials

Site	Injection Cycles ¹	Duration of Injection ²	Volume Injected ²	Average Injection Rate	Backwash Rate	Backwash Volume ²	Average Production Rate	Duration of Production
		days	ML	ML/d	ML/d	ML	ML/d	days
Jandakot	5	13 to 162	50 to 640	1.3 to 4.6	2 to 8.4	3.3 to 13.3	2 to 8.4	39 to 325
Mirrabooka	3	59 to 110	190 to 560	2.0 to 7.5	0 to 9.5	0.2 to 1	4 to 9.5	43 to 233
Beenyup ³	1	814	2,620	2.5 to 4.3	NA	NA	NA	NA

1) An injection cycle represents a continuous period of injection (discounting unplanned or operational shutdowns), followed by a period of residence and/or extraction.

2) During one injection cycle

3) At 1 February 2013. NA = Not applicable

Five injection/extraction cycles were conducted in the purpose-built ASR bore at Jandakot, with injection occurring for periods of between 13 and 162 days at rates of between 1.3 and 4.6 megalitres per day (ML/d). Between 50 and 640 ML of potable water were injected to the aquifer during each of these recharge events. The bore was generally backwashed to remove trapped suspended-sediment from the bore/aquifer interface every two to four days for 15 to 30 minutes during Cycles 1 and 2, and daily for 15 minutes during Cycles 3 to 5. Backwash rates tended to decrease with time during each cycle due to a reduction in bore efficiency. During Cycles 1 and 2, five per cent of the total water volume recharged was extracted during the backwash events, compared with two to three per cent during Cycles 3 to 5. Following injection and a period of residence in the aquifer the water was recovered by pumping. During extraction the bore was surge backwashed every eight hours for about 15 minutes to further facilitate bore redevelopment. The average production rate ranged from about 2.2 to 8.4 ML/d, depending largely on the bore efficiency, and production continued for between 39 and 325 days.

Three injection/extraction cycles were conducted at Mirrabooka with recharge occurring for periods of 59 to 110 days at rates of between 2.0 and 7.5 ML/d. Between 190 and 560 ML of potable water were recharged to the aquifer during each of these injection events. The bore was only occasionally backwashed during Cycle 1 at a rate of 7 ML/d for 15 to 20 minutes; it was backwashed at a rate of about 7 ML/d, daily for the first two weeks during Cycle 2, then on several occasions thereafter; and at varying intervals and duration and at different rates during Cycle 3. Between 0.2 and 1 ML of recharged water was recovered during these backwash events representing between 0.1 and 1.2 % of the total volume of water recharged. Following injection and a period of residence in the aquifer the water was recovered by pumping. During extraction for Cycle 3 the bore was surge backwashed every four hours for about 15 minutes to further facilitate bore redevelopment. The average production rate ranged from about 4 to 9.5 ML/d, and production continued for between 43 and 233 days. All backwash and recovered water was sent to the Mirrabooka Groundwater Treatment Plant prior to distribution in the IWSS.

There has been injection only at Beenyup, with extraction planned to take place from distant production bores in the future. Recharge commenced in November 2010, and has continued for over 814 days with occasional shut-downs related to the AWRP. More than 2,620 ML of reclaimed water has been recharged to the aquifer at rates of between 2.5 and 4.8 ML/d, depending on the treatment plant output. No backwash facilities have been installed in this bore and to date no redevelopment has been required.

Clogging Assessment

Clogging rates were generally assessed by comparing rates of water level rise in the injection bore with those in the nearby monitoring bores; and the degree of clogging and the effectiveness of backwashing and bore redevelopment was assessed using changes to the specific capacity of the injection bore:

$$Sc = \frac{Q}{h_0 - h}$$

Where Sc = specific capacity, Q = pumping (or injection) rate, and $h_o - h$ = water level drawdown (or rise).

Jandakot

At Jandakot, a comparison between the water-level rise in the ASR bore and the 15 m observation bore suggested that 80 to 85% of the water-level rise in the ASR bore was attributable to clogging (Rockwater, 2004 and 2008). This was supported by the decline in the specific capacity of the bore from a maximum of almost 350 m³/d/m at the start of injection to about 50 m³/d/m by the end of most injection cycles, as shown in the example from Cycle 3 (Figure 4).

An assessment of clogging rates, based on the difference in ASR bore water-levels measured every 24 hours and normalised to volume of water recharged, showed clogging rates generally increased with time and cumulative recharge volume, and also in response to specific poor water-quality events, particularly periods with elevated iron concentrations, high turbidity and/or high MFI, with clogging rates generally between 0.5 and 1.5 m/ML (Rockwater 2004, 2006 and 2008). It was also found that as the cumulative recharge volume increased, the backwash efficiency was reduced (Rockwater 2008). Aquifer recharge was effectively prolonged with bore backwashing and by reducing injection flow rates, as required, to maintain injection heads at a predetermined pressure. Clogging was effectively remediated following each injection cycle by implementing surge-backwashing every eight hours during the recovery pumping phase. This technique was effective in redeveloping the ASR bore, returning the specific capacity of the bore to around 250 m³/d/m (Figure 4).

It was concluded that clogging at Jandakot was mainly due to suspended solids in the recharge water, and that daily backwashing of the ASR bore decreased the amount of clogging and enabled a greater volume of recharge over a longer period. It did not, however, prevent clogging. It was also noted that the automated backwashing was most effective for reducing clogging close to the bore, and that once clogging occurred further into the aquifer, long-term pumping and surge-backwashing was required to recondition the bore. The operation of the dedicated backwashing system mitigated the need for more-frequent bore redevelopment using alternative methods such as air-lifting.

Mirrabooka

At Mirrabooka, a greater emphasis was placed developing an online tool to monitor clogging during injection, and a system was established to monitor the difference in water-levels between the ASR bore and the monitoring bores with time. When plotted, a flat trend represents no clogging and a continual rising trend indicates clogging (after Hutchinson, 1993, as presented by Centre of Groundwater Studies, 2004). The results from the shallower 15 m observation bore over the three injection cycles are shown in Figure 5. It should be noted that because there are only a few manual water-level measurements, and a number of changes were made to transducer levels and pressure range during the trials, it is not possible to be certain as to the absolute difference between the ASR bore and observation bore water-levels. However, the trend in the water level difference is considered reliable. In addition, data representing changes to water levels during water quality sampling events and during periods of no flow and early start up following a shut-down or backwashing event have been deleted for clarity.

Figure 5 shows minor and gradual clogging occurred during Cycle 1, and clogging rates were calculated to be in the order of 0.004 to 0.05 m/ML (Rockwater, 2010). Water levels in the ASR bore remained well below ground level and the specific capacity of the bore decreased from about 550 to 350 m³/d/m (Rockwater, 2010). There were only three backwash events, which yielded some improvement in specific capacity, but did not noticeably change the rate of clogging. There was no surge backwashing during recovery pumping, and no improvement was observed in the specific capacity of the ASR bore as a result of pumping alone. Clogging rates were an order of magnitude lower than those observed at Jandakot, and this was attributed to a better quality recharge water (lower iron and manganese concentrations and lower MFI) (Rockwater, 2010).

During Cycle 2, there was no notable clogging early in the trial for flow rates of either 3 or 5 ML/d (Figure 5), although the specific capacity of the ASR bore did decrease slightly (Rockwater, 2011). Technical difficulties encountered with the pressure transducers and flow meter resulted in a significant loss of data throughout this Cycle, and there were also problems in maintaining injection flow rates in the desired range. From the data available, however, it can be seen that clogging rates increased significantly following a shut-down event (consistent

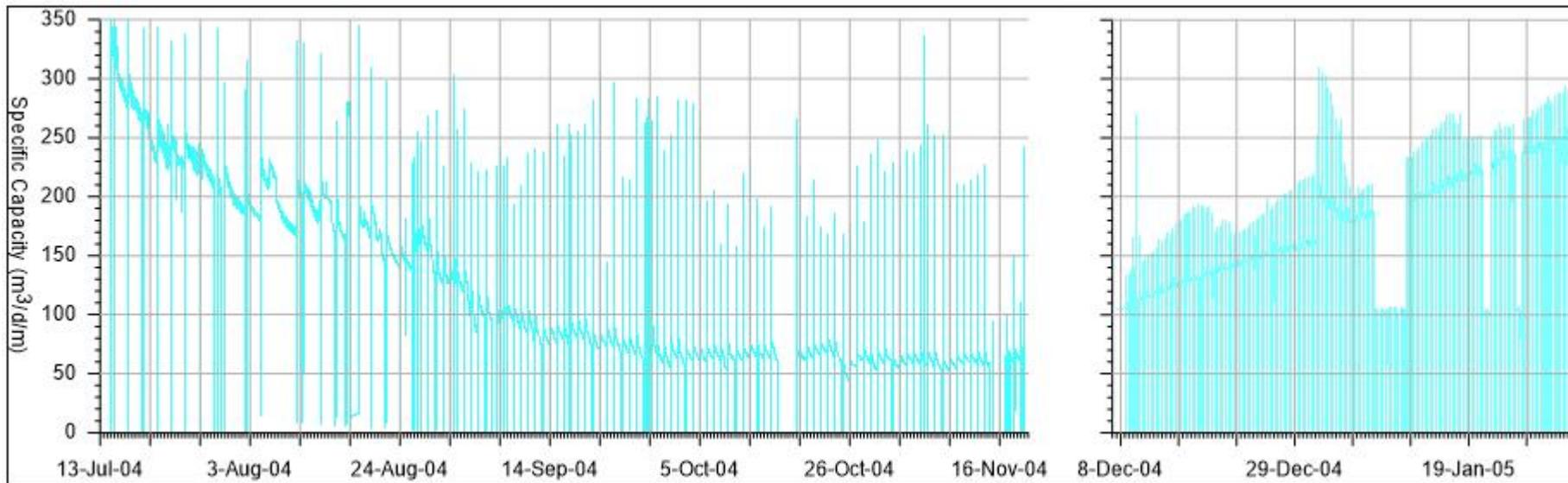


Figure 4: Changes to Jandakot injection bore specific capacity during Cycle 3- injection and extraction

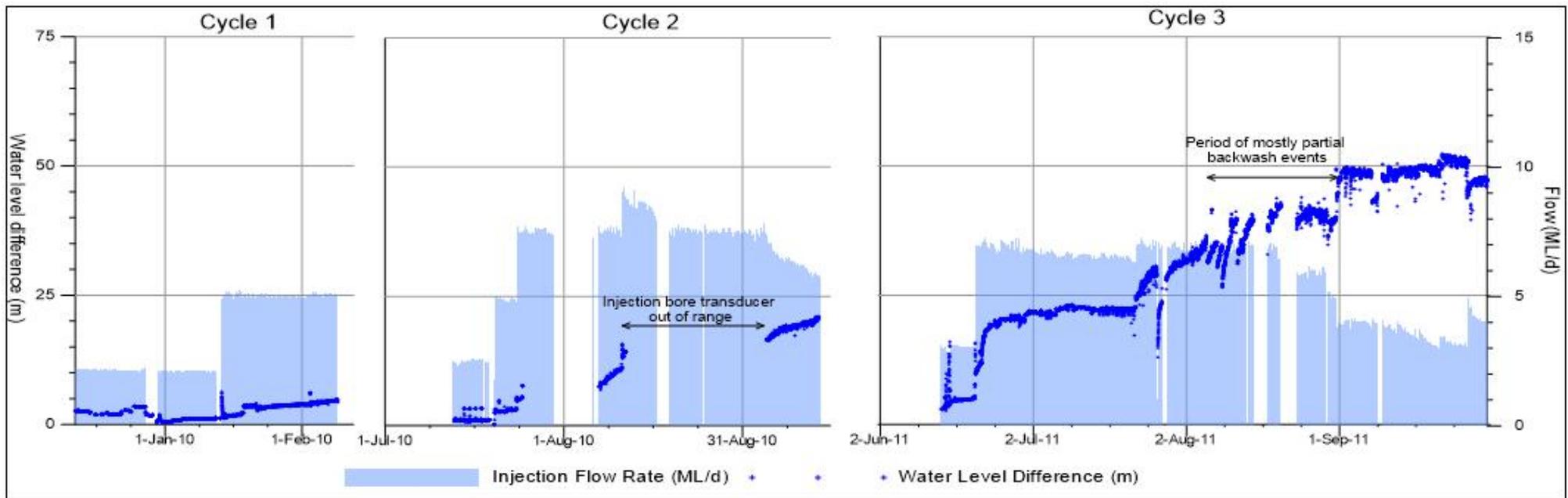


Figure 5: Water level difference between Mirrabooka ASR bore and 15 m observation bore showing clogging trends over the three injection cycles

with a reduction in specific capacity to 250 m³/d/m (Rockwater, 2011)) and over the last week of the trial (Figure 5). Backwashing occurred during the first week of the trial with only an occasional backwash thereafter. Clogging rates ranged from 0.0 to 0.9 m/ML, with maximum values increasing with depth in the bore (Rockwater, 2011). It was noted that significant clogging might be generated during start-up events and/or following an increase in injection flow rates. At the end of Cycle 2, heads in the ASR bore were well above ground level and the specific capacity had been reduced to less than 200 m³/d/m. Recovery pumping, which occurred without the surge backwashing, did not significantly improve the bore efficiency (Rockwater, 2011).

At the start of Cycle 3 clogging rates were very low, in the order of 0.01 to 0.04 m/ML for injection rates of 3 and 7 ML/d. They increased significantly, to between 0.07 and 0.11 m/ML, following a shut-down event and a reset of injection flow rates in late July 2011. In response to this increased clogging, a two week period of daily backwashing was initiated; however problems with the down-hole valve meant only a few of backwash events were effective, with low pumping rates and frequent recirculation of groundwater in the bore. It was noted that the water pumped from the bore during these backwashing events was highly turbid, and failed to clear even when pumped for an extended period. It is possible that siltstones and shales within the aquifer zone were fretting from an open section of the annulus, where a natural gravel pack had not been developed as anticipated. This is consistent with the steepening trend in start-up water-level difference (Figure 5), which suggests increased clogging with each partial or failed backwash event. From the end of August 2011, there was only one backwash event, and water-levels in the ASR bore were maintained at 20 m above ground level by reducing injection flow rates as required. Clogging rates were in the order of 0.2 m/ML, and were again noted to increase with the depth of the aquifer interval monitored (Rockwater, 2012). The specific capacity of the ASR bore decreased from about 260 to 60 m³/d/m during this Cycle (Rockwater, 2012). Surge backwashing was implemented every four hours during recovery pumping and the specific capacity of the ASR bore showed some improvement, increasing from 210 to 280 m³/d/m over the first two weeks of pumping. There was no further improvement over the following two months of pumping, even with continued surge backwash redevelopment (Rockwater, 2012).

It was concluded that the clogging at Mirrabooka was due largely to the remobilisation and compaction of aquifer fines, particularly at the bore/aquifer interface. It is believed that recirculation of aquifer sediments and their incomplete removal from the bore during backwashing contributed significantly to the injection pressure in the ASR bore, particularly on start-up, and this was most likely exacerbated by the absence of gravel pack around the bore screens. Increased clogging with time and injection volume was also evident, which is consistent with the results from Jandakot. It was found that recovery pumping alone was insufficient to recondition the ASR bore, but that surge backwashing was able to improve bore efficiency. The results were not as good as at Jandakot, however, and this could be due to the different bore construction or because clogging extended further into the aquifer by the end of the third cycle of injection.

Beenyup

At Beenyup, clogging in the recharge bore is monitored using a water-level rise differential method, as developed at Mirrabooka and further refined to normalise for potentiometric head difference with depth and changes in recharge flow rates. Figure 6 shows the average change in the water-level rise differential between the recharge bore and the five monitoring bores at the 20 m observation site, normalised to the injection flow rate, using the following equations:

1. $\Delta WL = SWL_{t_0} - WL_{t_n}$

Where ΔWL = change in water level from immediately prior to injection (SWL_{t_0}) to any given time (WL_{t_n});

2. $\Delta WL_{\uparrow} = \Delta WL_R - \Delta WL_{Obs}$

ΔWL_{\uparrow} = difference in water-level rise between the recharge bore (ΔWL_R) and each observation bore (ΔWL_{Obs});

3. $N\Delta WL_{\uparrow} = \Delta WL_{\uparrow} - (aQ + b)$

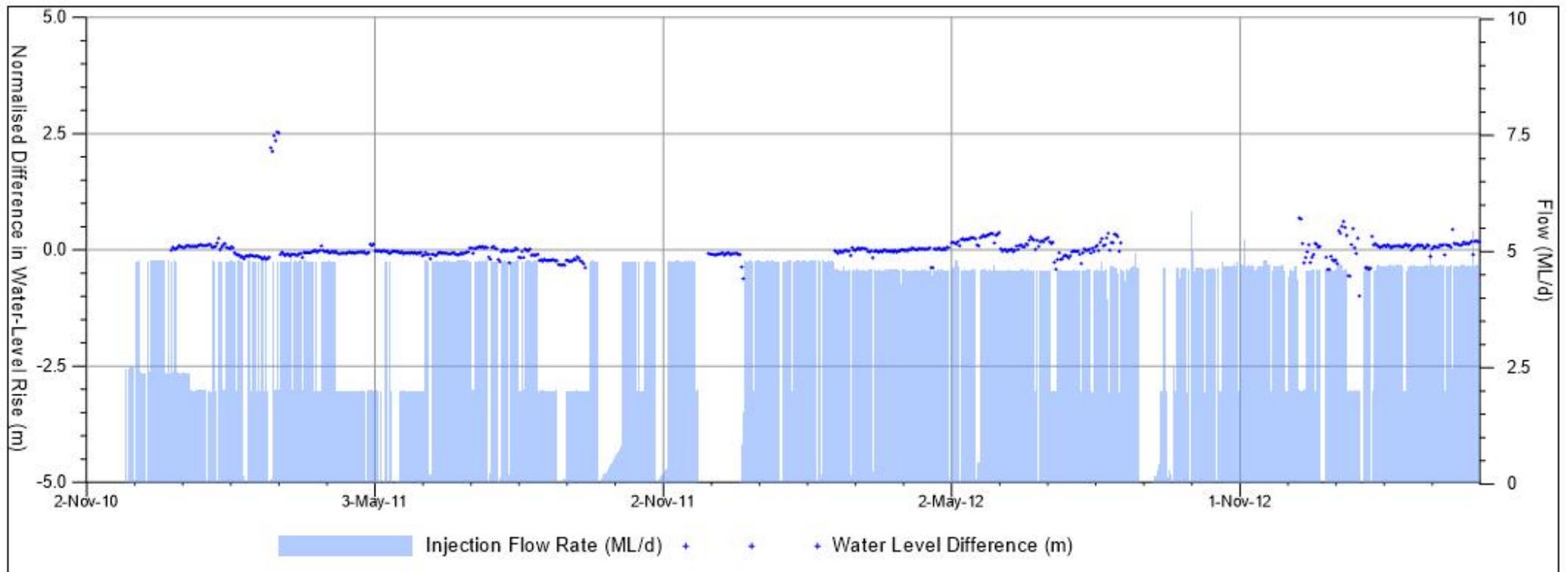


Figure 6: Normalised water-level rise differential averaged over the five monitoring intervals 20 m distant from the recharge bore

Where $N\Delta WL_{\uparrow}$ = difference in water level rise between the recharge bore and each observation bore normalised to a constant flow rate, a = slope of the line for the plot of recharge rate (Q) vs. the difference in water level rise (ΔWL_{\uparrow}), and b = the intercept at zero flow. The average $N\Delta WL_{\uparrow}$ is the average of those normalised values calculated for each of the five individual observation bores.

It can be seen from the almost completely flat trend in the water-level difference between bores, that very little clogging has occurred at Beenyup in response to recharge of the reclaimed water. In general, the head build up in both the aquifer and the recharge bore has been less than 5 m for recharge rates of up to 5 ML/d. The lack of clogging is likely to be due largely to the absence of suspended solids in the recharge water, and although there is evidence of mobilisation of colloidal fines in the aquifer itself (Water Corporation, 2012), this does not appear to be contributing significantly to clogging at this site. There may have been some low levels of clogging between April and June 2012, which correlates to a period of increased microbial activity, and is consistent with observed denitrification at the site, suggesting some minor microbial clogging may have occurred. Water levels have since stabilised, and no further clogging is evident. A clogging alert level is set at the normalised water-level rise differential of 5 m.

Clogging at Beenyup is currently assessed weekly following manual download and manipulation of the monitoring data. In the future it is anticipated that the system will be fully automated and available on-line to operators at the GWR site.

No bore redevelopment has been required to date. Future down-hole investigations, backwashing and pumping tests to assess the bore performance are planned to be conducted during the next period of extended shut-down at the treatment plant.

Conclusions

Managed aquifer recharge to the confined Leederville aquifer has been extensively trialled and assessed in the Perth metropolitan area by the Water Corporation over the last thirteen years. The studies have shown a general consistency between aquifer characteristics and aquifer response, and have confirmed the technical viability of large-scale recharge of potable and reclaimed water to the aquifer as a means of protecting and potentially increasing groundwater supplies.

From the results of the trials, it is clear that the quality of the recharge water is important in determining the degree of clogging from suspended solids, with very small amounts of suspended sediment – particularly when associated with iron and manganese, contributing significantly to the clogging. Comparison of the results from Jandakot and Mirrabooka suggest that the degree of clogging associated the recharge water could be determined prior to injection by measuring MFI: MFI values of up to 14 L/s² appear to be readily acceptable in this coarse sandstone aquifer. Particle size analysis has shown that particles <10 μ m in diameter are responsible for the clogging observed at Jandakot.

It is likely that the predominant cause of clogging at Mirrabooka was the remobilisation of aquifer fines, particularly at the aquifer/bore interface. It is believed that the absence of gravel pack around the screens contributed significantly to the problem, with fretting and recirculation of aquifer fines occurring, particularly during start-up and backwash events. Contrary to findings at other locations, this method of bore construction does not appear suited to the conditions in the Leederville aquifer (weakly consolidated, interbedded sandstone, siltstone and shale).

While dedicated bore backwashing techniques have been shown to effectively reduce the severity of clogging, increase the recharge volume and extend the duration of injection, it does not prevent clogging and regular periods of redevelopment are required. Utilising the pump system to facilitate surge backwashing during recovery pumping has also been shown to be an effective method of bore redevelopment, significantly increasing the time between more traditional bore development methods, such as air-lifting. It should be noted, however, that this method has been difficult to implement at an operational level, with common technical difficulties and the additional

requirement to dispose of sometimes large amounts of very poor quality backwash water. Neither of the trial schemes have continued to a fully operational site.

The most successful site has been Beenyup, where the recharge water has been of such high quality that significant clogging has not occurred, and recharge operations are set to continue into the foreseeable future.

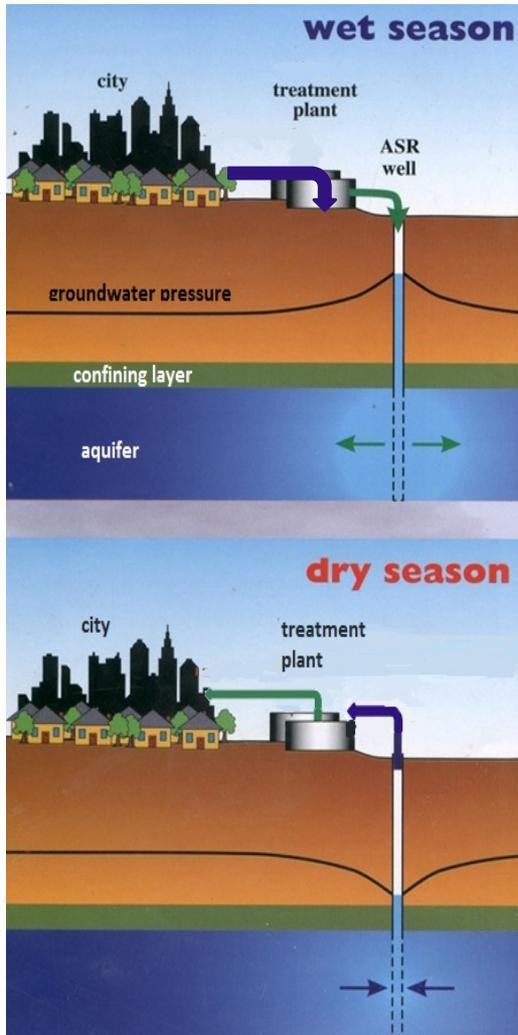
References

- Centre for Groundwater Studies, 2004. 4th ASR national workshop: management of aquifer recharge. Notes and PowerPoint presentations, October 2004.
- Davidson, W. A., 1995, Hydrogeology and groundwater resources of the Perth Region, Western Australia: Western Australian Geological Survey, Bulletin 142.
- Davidson W.A., & Yu, X, 2008, Perth regional aquifer modelling system (PRAMS) model development: Hydrogeology and groundwater modelling, Western Australia Department of Water, Hydrogeological record series HG 20.
- Gerges N.Z., 1999. Methods of well completion for ASR wells and injection testing. Centre for Groundwater Studies, 4th ASR national workshop: management of aquifer recharge. Notes and PowerPoint presentations, October 2004.
- Leyland, L., 2011. Hydrogeology of the Leederville Aquifer, Central Perth Basin, Western Australia. Thesis presented for the degree of PhD. University of Western Australia, School of Earth and Environment, July 2011.
- NHMRC, 2011. Australian drinking water guidelines Paper 6 National water quality management strategy. National Health and Medical Research Council and the Natural Resource Management Ministerial Council, Canberra.
- Prommer, H., Descourvieres C.D., Handyside, M., Johnston, K., Harris, B., Li, Q., Costello, P., and Martin, M., 2011. Interim Report – Aquifer storage and recovery of potable water in the Leederville Aquifer. CSIRO: Water for a Healthy Country National Research Flagship
- Rockwater, 2004. Jandakot aquifer storage and recovery project. Results of Cycles 1 & 2: operational pilot. Unpublished report to Water Corporation of Western Australia, November 2004.
- Rockwater, 2006. Jandakot aquifer storage and recovery project. Results of Cycles 3 & 4: operational pilot. Unpublished report to Water Corporation of Western Australia, July 2006.
- Rockwater, 2008. Jandakot aquifer storage and recovery project. Results of Cycle 5: operational pilot. Unpublished report to Water Corporation of Western Australia, November 2008.
- Rockwater, 2010. Mirrabooka aquifer storage and recovery trial. Results of Cycle 1: December 2009 – April 2010. Unpublished report to Water Corporation of Western Australia, October 2010.
- Rockwater, 2011. Mirrabooka aquifer storage and recovery trial. Results and technical review for Cycle 2: July 2010 to January 2011. Unpublished report to Water Corporation of Western Australia, October 2011.
- Rockwater, 2012. Mirrabooka aquifer storage and recovery trial. Results and technical review for Cycle 3: June 2011 to January 2012. Unpublished report to Water Corporation of Western Australia, December 2012.
- Segalen, A-S., Pavelic P. & Dillon P., 2005. Review of drilling, completion and remediation methods for ASR wells in unconsolidated aquifers. CSIRO Land and Water Technical Report No. 04/05. March 2005.
- Water Corporation, 2012. Groundwater Report 2012. Groundwater Replenishment Trial. Published by the Water Corporation of Western Australia, ISBN 1 74043 810 8, October 2012.

Hartfield Park

A MUNICIPAL SCALE ASR PROJECT

Aquifer Storage and Recovery (ASR)



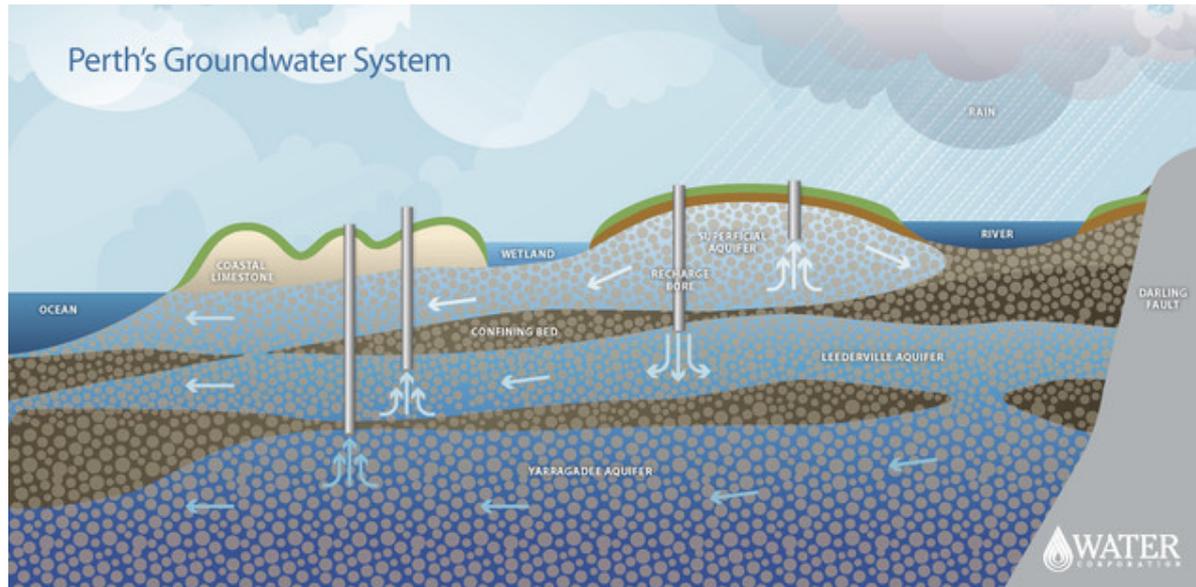
After CSIRO/Water Corporation

Injection and recovery of water from the same bore:

- Capture water that otherwise may have gone to waste
- Local storage using minimal land area
- No evaporative loss
- Replenish depleted aquifers
- Improve groundwater quality

Perth Experience

Water Corporation



Recharge of potable and tertiary treated wastewater into the deep, confined, sedimentary aquifers in Perth, Western Australia

Jandakot ASR Trial: 2000 - 2008



J5 – 10" Leederville Bore

Serpentine Water Main



Mirraboooka ASR Trial: 2009 - 2012



50 μm filtration unit



Dedicated monitoring bore

Images courtesy of Water Corporation

Beenyup: 2009 - present



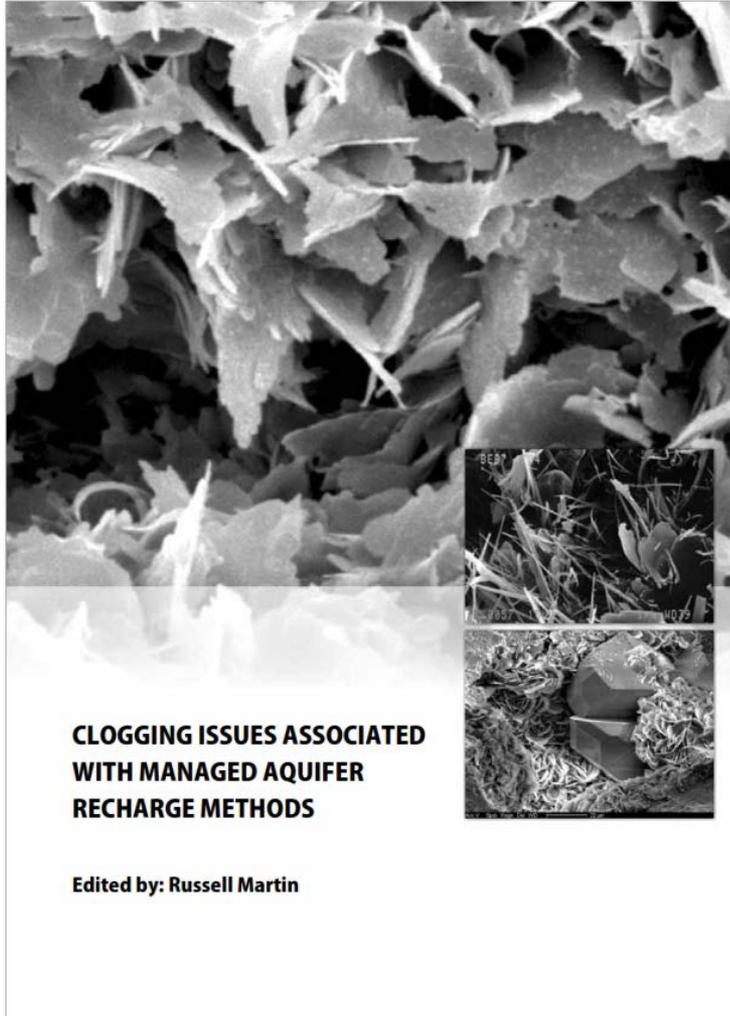
Advanced Water Recycling Plant

Images courtesy of Water Corporation



BNYP LRB1 – 10” Leederville Bore

Summary of Results – ISMAR 2013



Case Study: Recharge of Potable and Tertiary-treated Wastewater into a Deep, Confined Sandstone Aquifer in Perth, Western Australia

K. Johnston¹, M. Martin² and S. Higginson²

¹ Rockwater Pty Ltd

² Water Corporation, Western Australia

Abstract

The Water Corporation of Western Australia started investigating the feasibility of recharging potable water into the deep, confined aquifers beneath the Perth Metropolitan area, Western Australia, in 2000. Managed aquifer recharge (MAR) was identified as a potentially significant operating strategy for the Integrated Water Supply Scheme with possible benefits to the environment and providing drought security, improved groundwater quality, groundwater banking and maintenance of groundwater levels.

Perth is largely dependent on groundwater for its municipal water supply, with up to 50% of the total supply sourced from the vast groundwater system that underlies the region. The Perth groundwater system is part of the Perth Basin, and is bounded in the east by crystalline rocks of the Yilgarn Craton and extends many kilometres off shore to the west. The onshore portion of the aquifer stretches 250 km along the coast in a narrow strip of clastic sediments that are more than 2,000 m deep. The sediments have been laid down under varying depositional environments over millions of years. The groundwater system can be broadly divided into three main aquifers: the shallow, unconfined superficial aquifer, and the deep, confined Leederville and Yarragadee aquifers. The Leederville aquifer has been the target aquifer for MAR to date, and there are plans to incorporate the deeper Yarragadee aquifer into future groundwater replenishment operations.

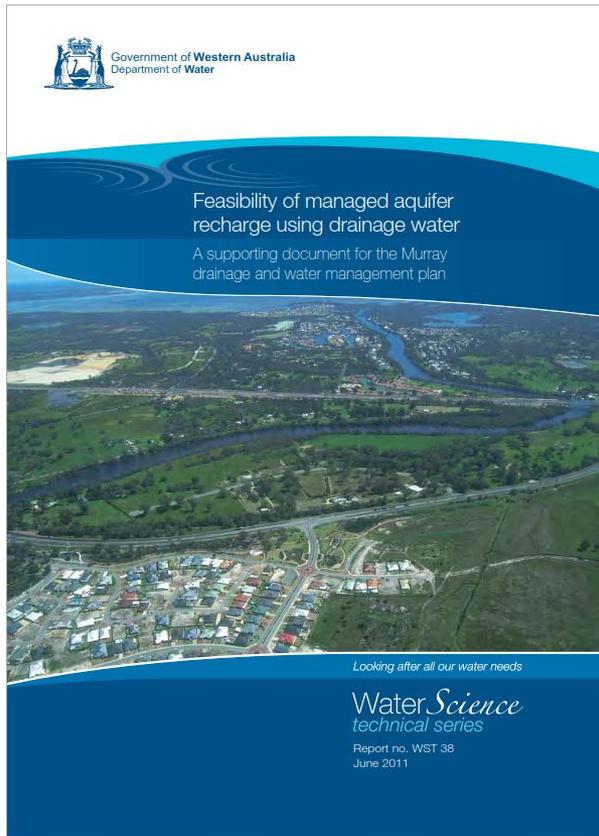
The Leederville aquifer is a major confined aquifer that is typically between 150 and 400 m thick. It is subdivided into three members:

- The Pinjar Member comprises mainly thin sandstone beds interlayered with siltstone and shale. It generally acts as an aquitard and conformably overlies the Wanneroo Member;
- Individual sandstone beds of the Wanneroo Member are about 10 to 20 m thick, with interlayered siltstone and shale beds of varying thickness. The sandstone beds are weakly consolidated and composed predominantly of coarse-grained, poorly-sorted quartz. The aquifer transmissivity is in the order of 500 to 2,000 m²/d/m, and groundwater salinity is generally between 250 and 1,000 mg/L TDS. The Wanneroo Member is the target zone for aquifer recharge and conformably overlies the Mariginiup Member;
- The Mariginiup Member consists of thinly interbedded siltstone and shale with few very thin sandstone beds. It acts as a confining layer.

Investigations commenced with the establishment of a small aquifer storage and recovery (ASR) trial at Jandakot, injecting potable surface water into an existing production bore. The preliminary trial was successful, with clogging managed by backwash-pumping techniques. This facility was upgraded to a pilot scale operation with a new recharge bore and associated infrastructure. Having demonstrated the technical feasibility of ASR in the Leederville aquifer, a large scale ASR site was established at Mirrabooka, where potable treated-groundwater was recharged to the aquifer at rates up to 7 ML/d. Clogging was similarly managed using backwash-pumping

Hartfield Park 2012

A Demonstration Site



Preliminary Feasibility Assessment

2012 Desktop Study

- Hartfield Park redevelopment
- Groundwater allocation at limit
- Alternate water supply
 - Woodlupine Main Drain
 - Require 50,000 kL/annum
- Managed Aquifer Recharge
 - Superficial
 - Leederville

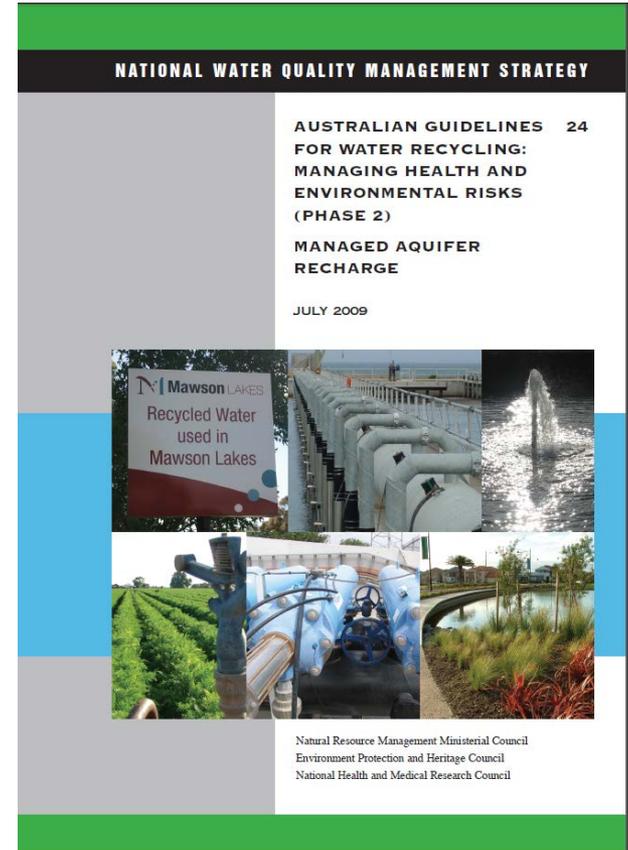
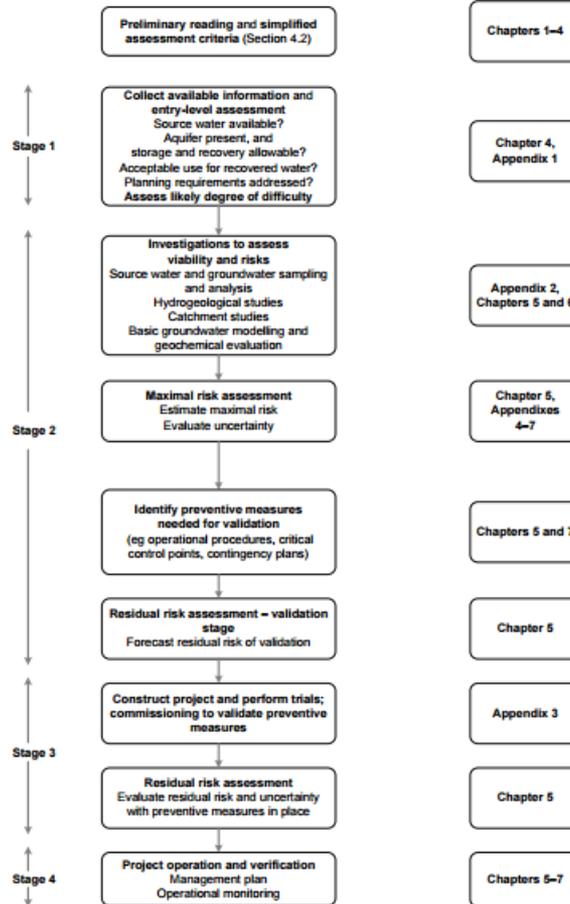


500 m

Australian MAR Guidelines

A systematic, risk-management approach

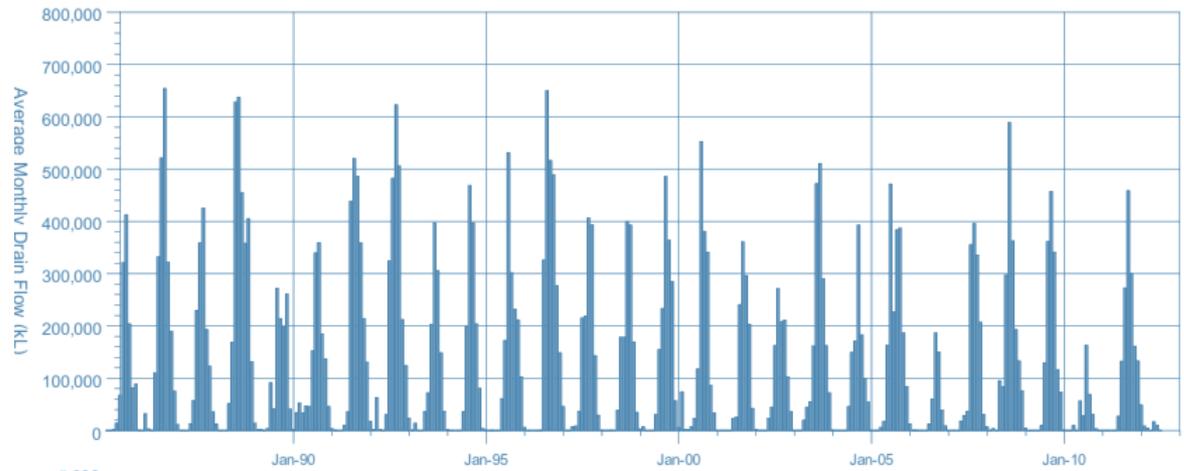
Stages of Project Development and Assessment



Australian MAR Guidelines (2009)

Stage 1 – Desktop Study

High level viability assessment using available information and data



Identified need/benefit



Source water available



Suitable aquifer present



Acceptable use for recovered water



Regulatory approval



Planning requirements identified



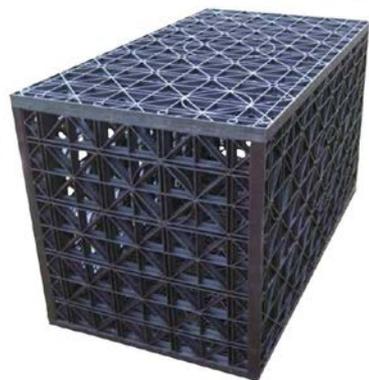
Information gaps?



Degree of Difficulty Assessment

Infiltration to superficial aquifer

Easy to implement



Few resources
Low level technical
expertise

Injection to Leederville aquifer

Difficult to implement



Many resources
High level technical
expertise

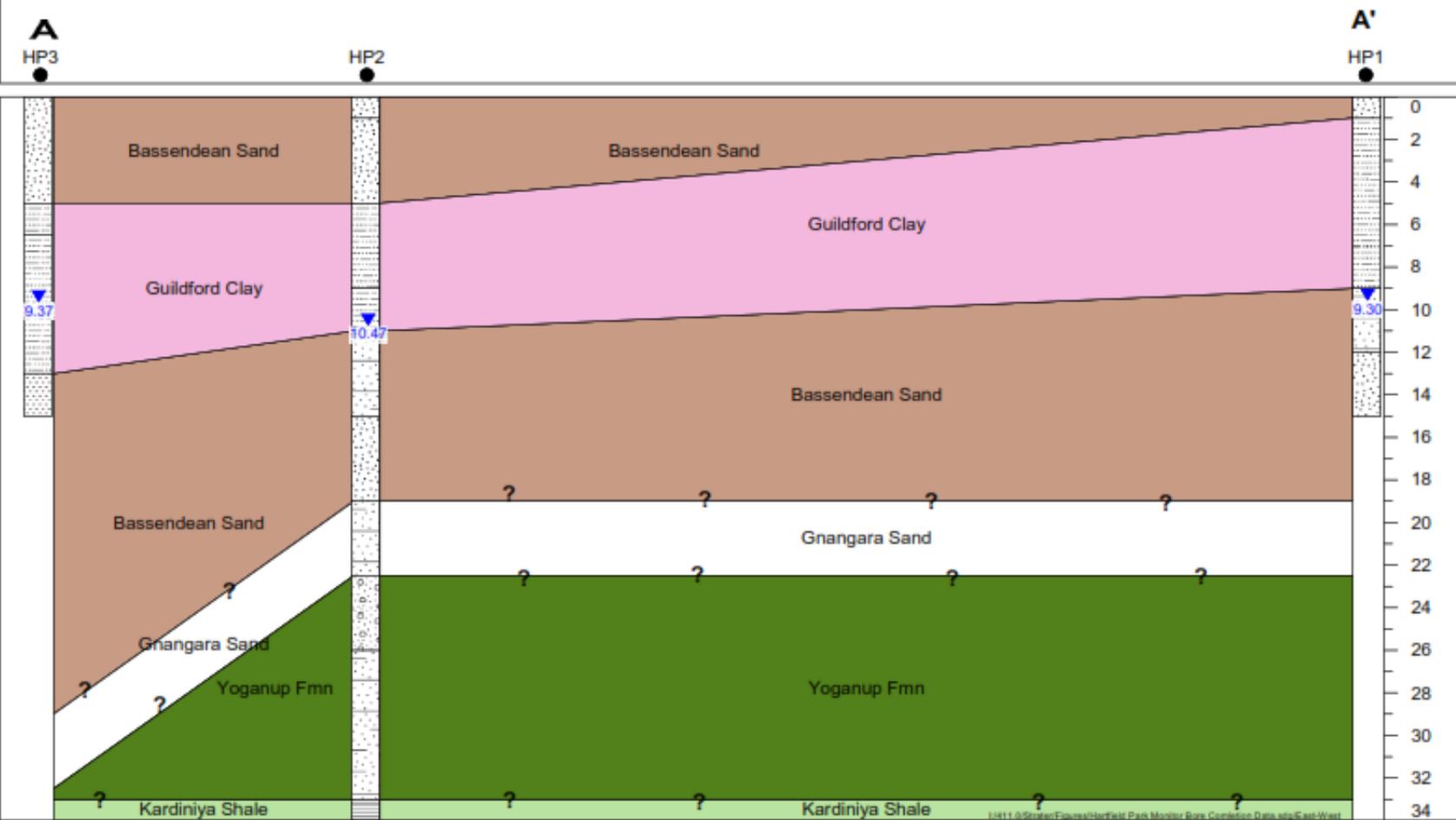
Stage 2 – Site Investigations and Risk Assessment

- Drilling Investigation
 - Geology
 - Mineralogy
 - Aquifer characteristics
 - Groundwater quality
- Source Water
 - Volume
 - Water quality
 - Connected ecosystems
- Risk Assessment
 - Key risks
 - Mitigating strategies
 - Residual risk
- Pilot Trial
 - Design and costing
 - Business Case



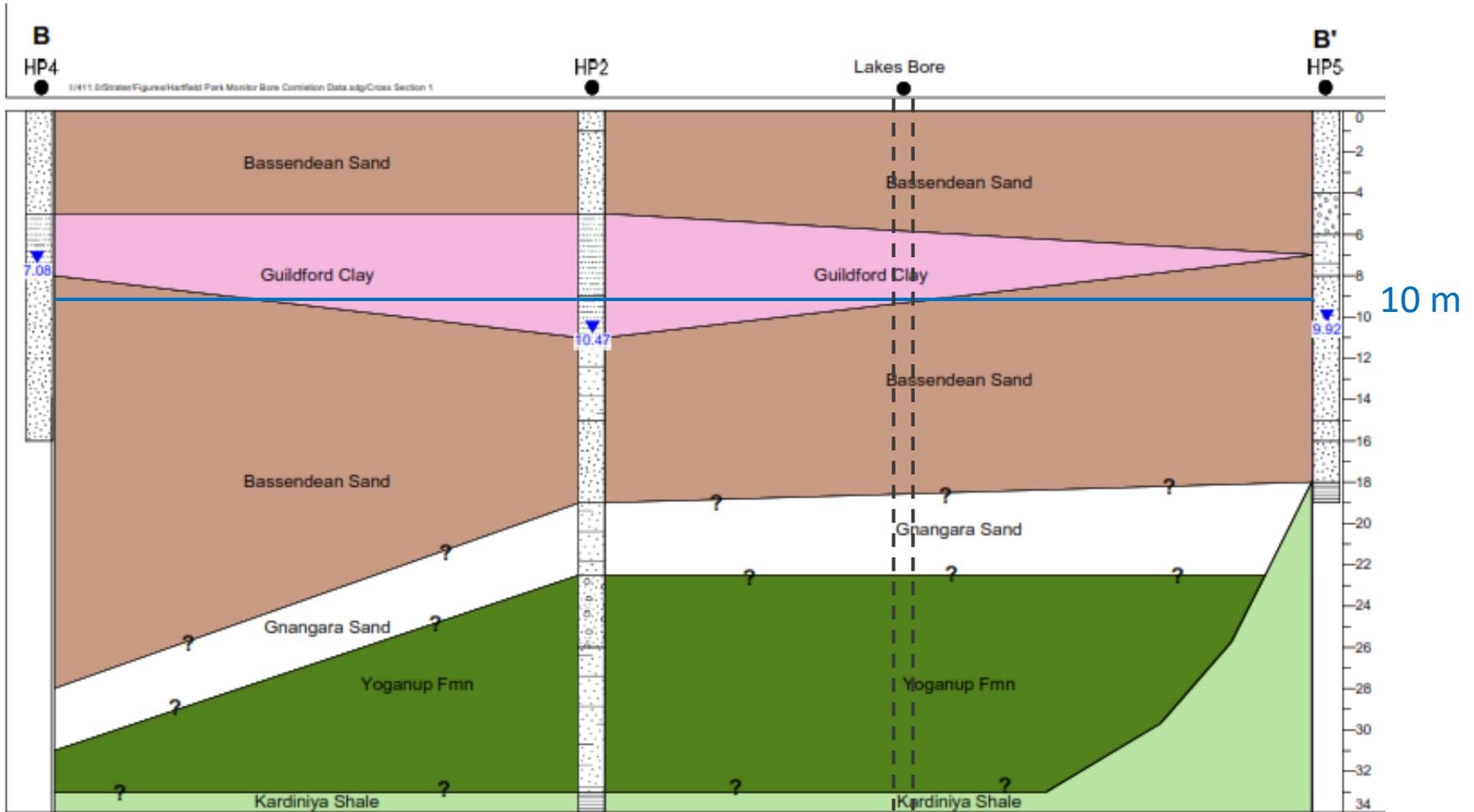
Drilling investigations – file photo

East – West Transect



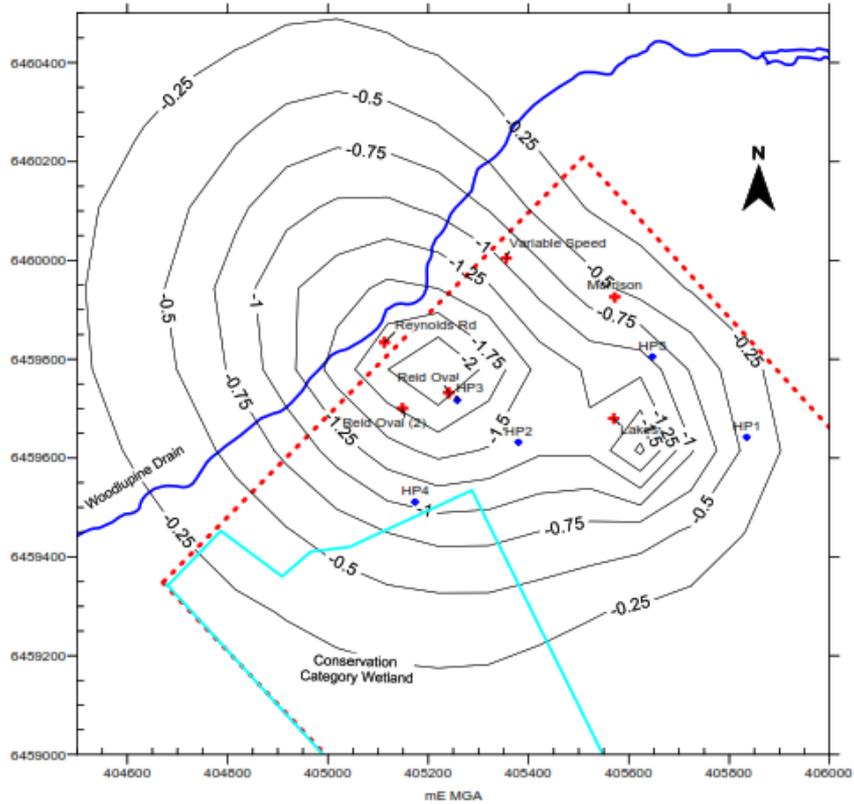
Rockwater, 2013

SW – NE Transect



Rockwater, 2013

Groundwater Modelling



Note: -ve value indicated rise in groundwater level



Rockwater, 2013

Risk Assessment

Table 6: Maximal and Residual Risk Assessment Summary for Hartfield Park MAR

MAR Hazards	Maximal Risk				Pre-commissioning Residual Risk			
	Human endpoint - irrigation	Environmental endpoint - irrigation	Environmental endpoint - Conservation Wetlands	Environmental endpoint - aquifer	Human endpoint - irrigation	Environmental endpoint - irrigation	Environmental endpoint - Conservation Wetlands	Environmental endpoint - aquifer
1 Pathogens - pathogens present in untreated stormwater. No water will be injected from first flush events.	H	L	L	M	L	L	L	L
2 Inorganic chemicals - none likely present at levels of concern for irrigation.	L	L	L	L	L	L	L	L
3 Salinity and sodicity - stormwater of better quality than groundwater.	L	L	L	L	L	L	L	L
4 Nutrients - nitreogen, phosphorous and organic carbon. None likely present at levels of concern for irrigation.	L	L	L	M	L	L	L	L
5 Organic chemicals - none likely of concern for irrigation.	L	L	L	M	L	L	L	L
6 Turbidity and particulates - not present at levels of concern for irrigation, but may cause clogging (operational risk).	L	M	L	H	L	L	L	L
7 Radionuclides - none likely present at levels of concern for irrigation.	L	L	L	L	L	L	L	L
8 Pressure, flow rates, volumes and groundwater levels. Small scheme in semi-confined aquifer. Injection pressures will need to be monitored and controlled.	N/A	L	L	M	N/A	L	L	L
9 Contaminant migration in fractured rock and karstic aquifers. Not applicable in Bassendean Sand aquifer.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
10 Aquifer dissolution and stability of well and aquitard - predominantly quartz aquifer.	L	L	L	L	L	L	L	L
11 Aquifer and groundwater-dependent ecosystems - aquifer likely confined by Guildford Clay beneath Conservation wetland. No direct connection anticipated.	N/A	L	L	L	N/A	L	L	L
12 Energy and greenhouse gas considerations - unknown compared to other options.	N/A	U	N/A	N/A	N/A	U	N/A	N/A

H = high risk; M = moderate risk; L = low risk; N/A = not applicable; U = unknown.

Rockwater, 2013

Stage 2 – Results

- Between 115 and 230 ML/annum storm-water for irrigation
- Superficial aquifer likely to be viable for storage
- Recharge via injection bores
- Identified risks can be mitigated
 - Water treatment
 - Bore selection
 - Site access controls
 - Full recovery of injected water
- Pre-commissioning trial recommended
 - 46 ML using an existing bore
- Regulatory approvals (WRMOS)

Table 8: Summary of Estimated Costs to Trial, Establish and Run the Proposed MAR Scheme

Item	Approximate Cost for Pre-commissioning Trial	Additional Cost to go to Full Scheme	Ongoing Operating Costs
	\$	\$	\$
Site Set-up			
Stormwater Take-off and Pump Station			
Filtration System*			
Delivery			
Commissioning			
Installation to mains	Not costed	Not costed	Not costed
Injection Bore Set-up			
Preparation of Operating Strategy to support DC groundwater licence application.**	25,000.00		
Consulting services to tender process	15,000.00		
Injection start-up, testing and reporting	7,500.00		
Maintenance and Re-commissioning			
Bore redevelopment	1,500.00		
Recommissioning Production bore	Not costed		
Monitoring and Assessment			
Measurement of flow rates and water levels	2,000.00		
Water sample analysis	5,000.00		
Hydrogeological consulting	45,000.00		
Total (excl. GST)	\$320,000.00	\$530,000.00	\$00,000.00

*Filtration costs represent two different systems: the first provides filtration for flow rates to 6L/s, the second provides filtration for flow rates to 30 L/s. Preliminary advice is that it is not possible to upgrade the first system to the higher flow rate
 **An Operating Strategy may need to be completed prior to the pre-commissioning trial depending on DoW requirements.

Rockwater, 2013

Stage 3 – Construction and Commissioning

- Construct infrastructure and perform trials
 - Confirm technical feasibility
 - Confirm mitigating strategies for risks are effective
- Identify any additional requirements
- Functional design
 - Design and cost full scale scheme
 - Business case for full scheme
 - Refine risk management plan



Filtration Unit Prior to Building Enclosure

Foothills Water Proofing Scheme – Shire of Kalamunda

Site Set-Up



- Take-off point with transfer pump
- Lake Bore retrofitted with injection valve and monitoring equipment
- Filtration plant



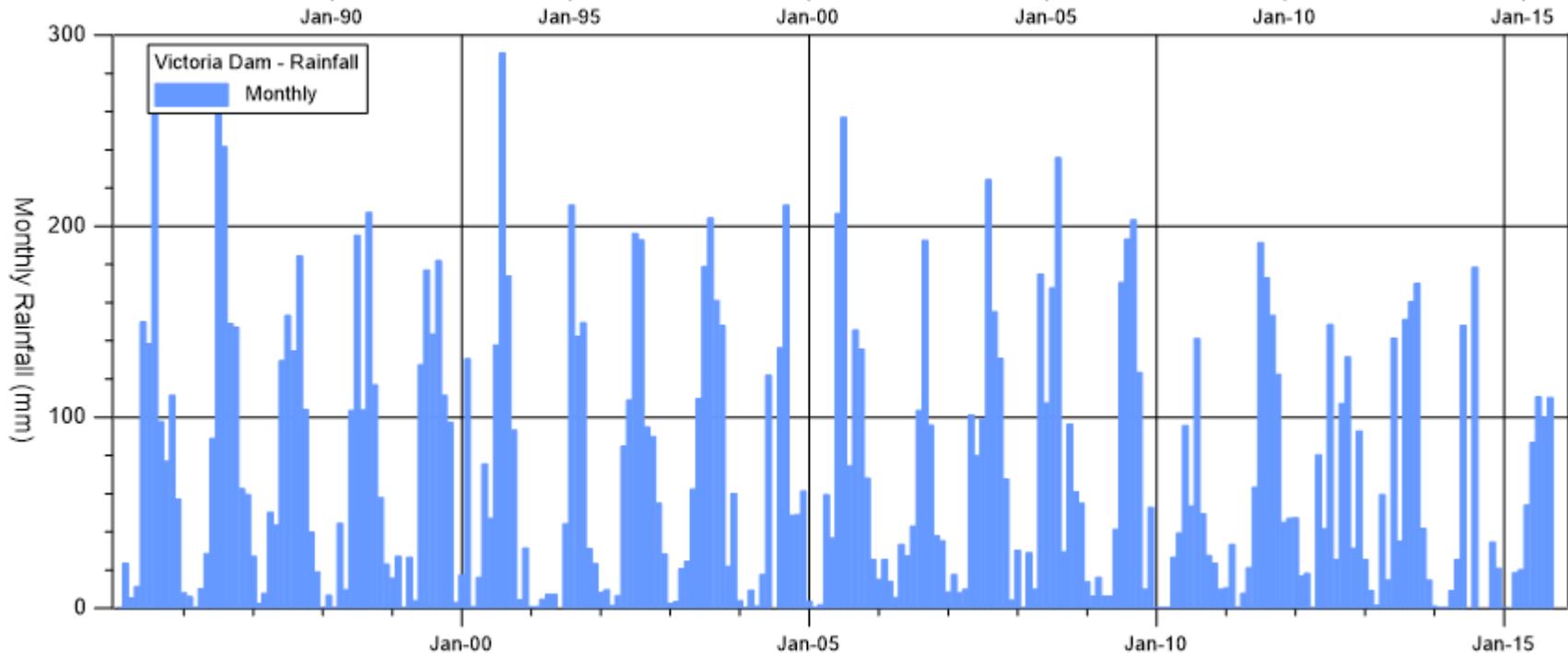
Woodlupine Main Drain

Foothills Water Proofing Scheme – Shire of Kalamunda

Preliminary Trial Operations

- Objective:
 - To confirm and validate technical viability of fully operational scheme
- Timing
 - Late-July to August 2015
- Extraction from drain once continuous flow established (46,600 kL allocated)
 - Extraction not to exceed 50% total flow in drain
- Filtration to remove TSS to 2 μm
- Recharge injection rates up to 8 L/s
 - Maximum injection pressure 50 kPa at surface
- Monitoring:
 - Injection flow rate
 - Stormwater quality (up-stream and down-stream of filtration unit)
 - Groundwater levels (injection bore and monitoring bores)
 - Groundwater quality (before and after injection)

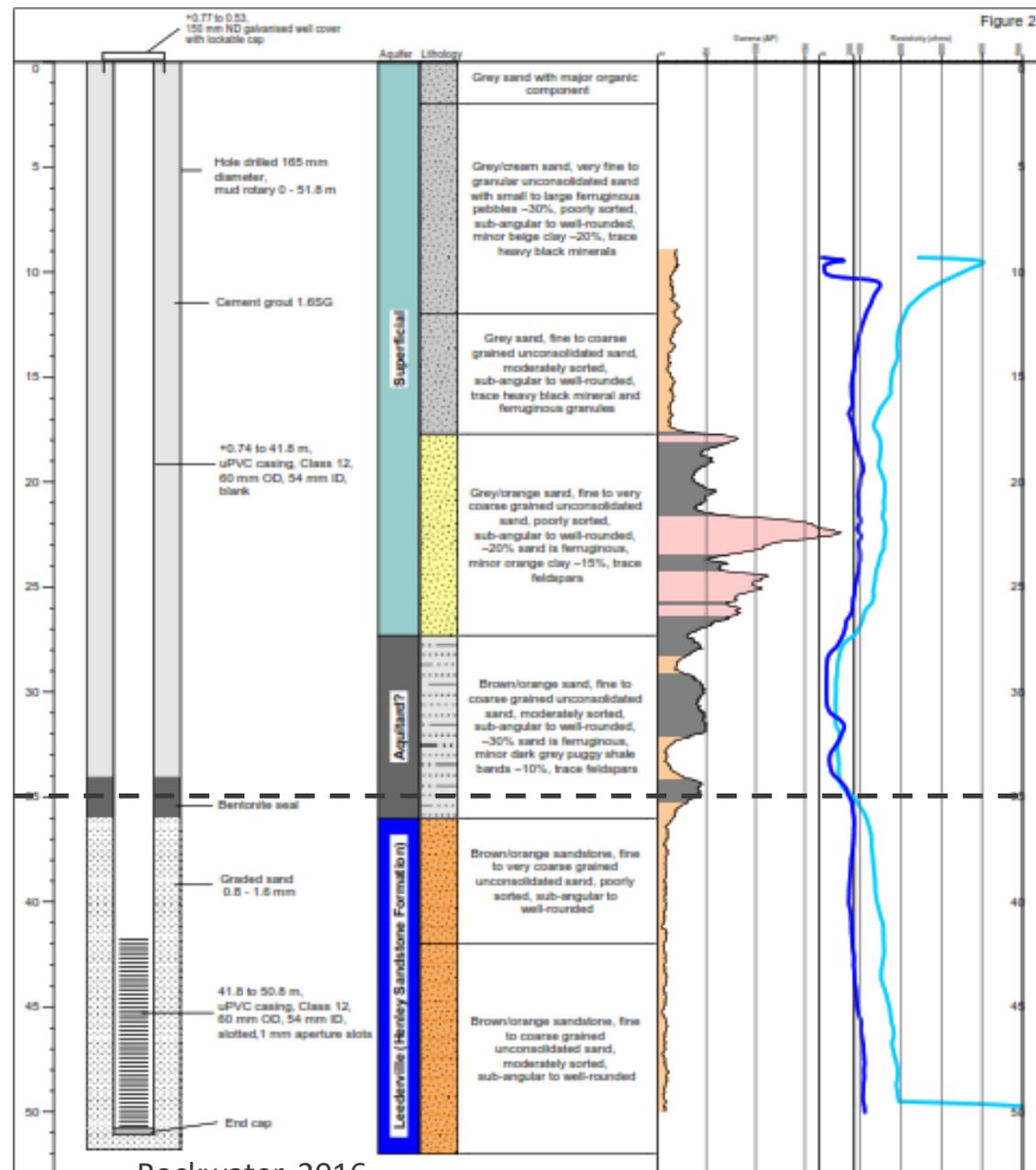
Interim Results



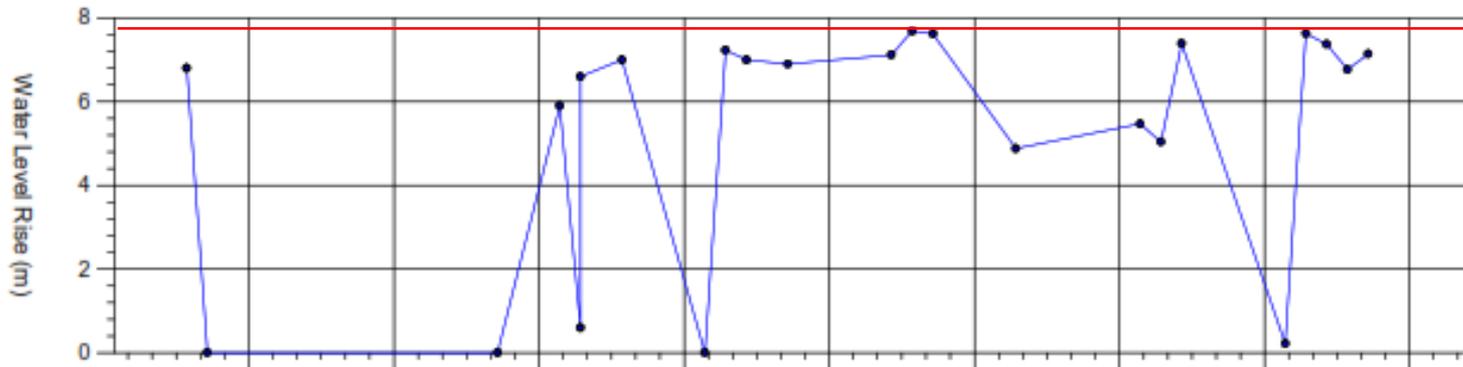
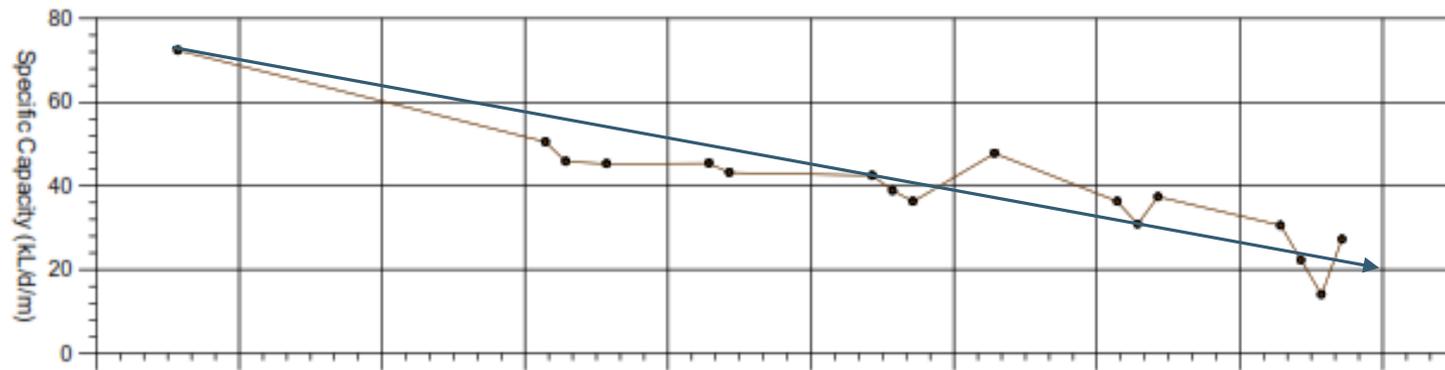
- One of the lowest rainfall years on record – comparable to 2010
- Difficulties commissioning filtration system and injection control
- Intermittent injection – total 0.44 ML stormwater captured

Revise Conceptual Hydrogeology

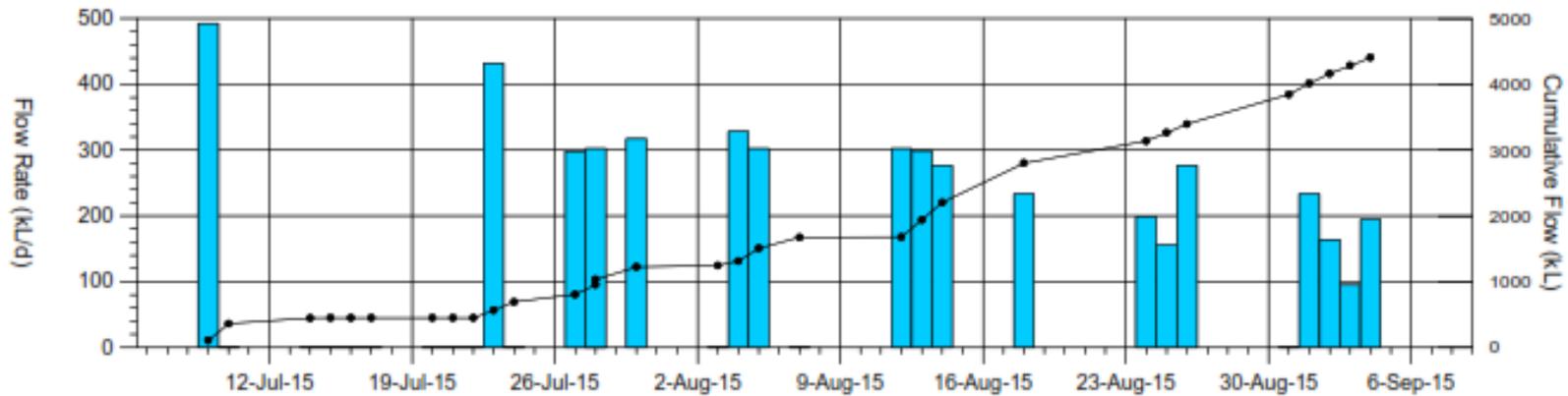
- CCTV Camera run:
 - Lake Bore screens between 39 and 48 m depth
- Monitoring Bore Drilled
 - 20 m SW Lake Bore
- Leederville Aquifer
 - Henley Sandstone
- Reported to DoW
- Opportunity to collect additional data
 - Mineralogy
 - Grain-size analysis



Rockwater, 2016



1.5 m bgl



Rockwater, 2015

CCTV Logs

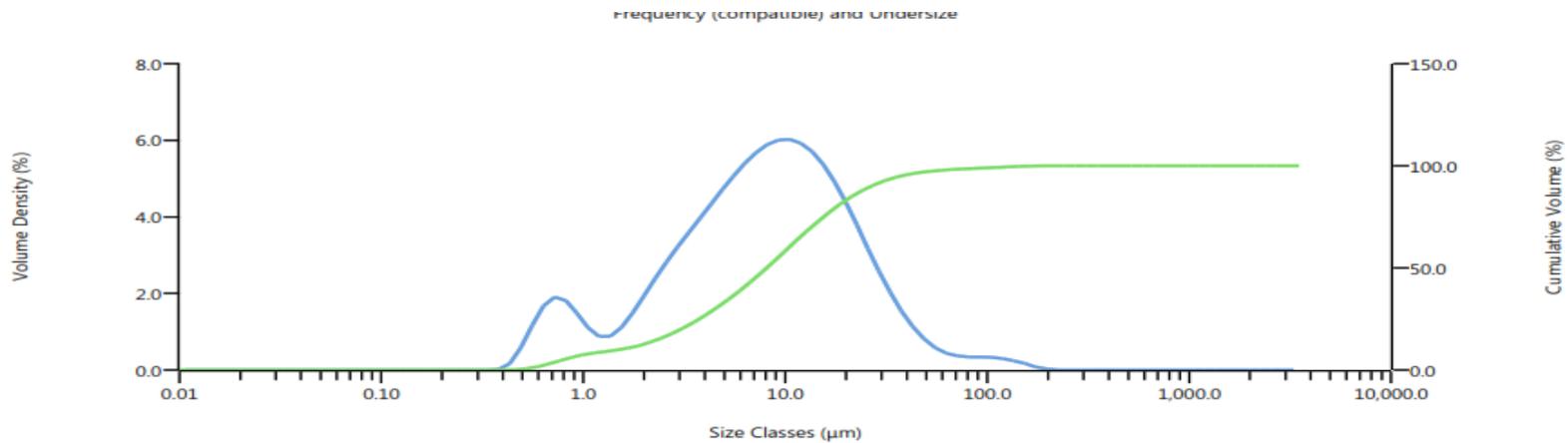


- A: Prior to trial and before air-lift development
- B: Prior to trial and after air-lift development
- C: Following trial and before air-lift development

← Iron-rich floc – biological in nature

Rockwater, 2015

Water Quality – Clogging Risk



Particle Size Analysis – July 2015 after rain

- Total Suspended Solids
 - Generally <1 to 2 mg/L
 - Up to 37 mg/L following heavy rainfall
- Particle Size Analysis
 - Generally >50 % particles < 10 µm
 - Up to 95 % particles < 10 µm end of season
- High levels iron bacteria in backwash following injection.

Water Quality – Contamination Risk

Metals: Al, Fe, Mn, Se

Heavy Metals: As, Cd, Cr, Cu, Co, Ni, Pb, Zn, Hg

Nutrients: Total Nitrogen (TN), Total Kjeldhal Nitrogen (TKN), Nitrite (NO₂), Nitrate (NO₃), Ammonia (NH₃), Total Phosphorus (TP)

Biochemical Oxygen Demand (BOD)

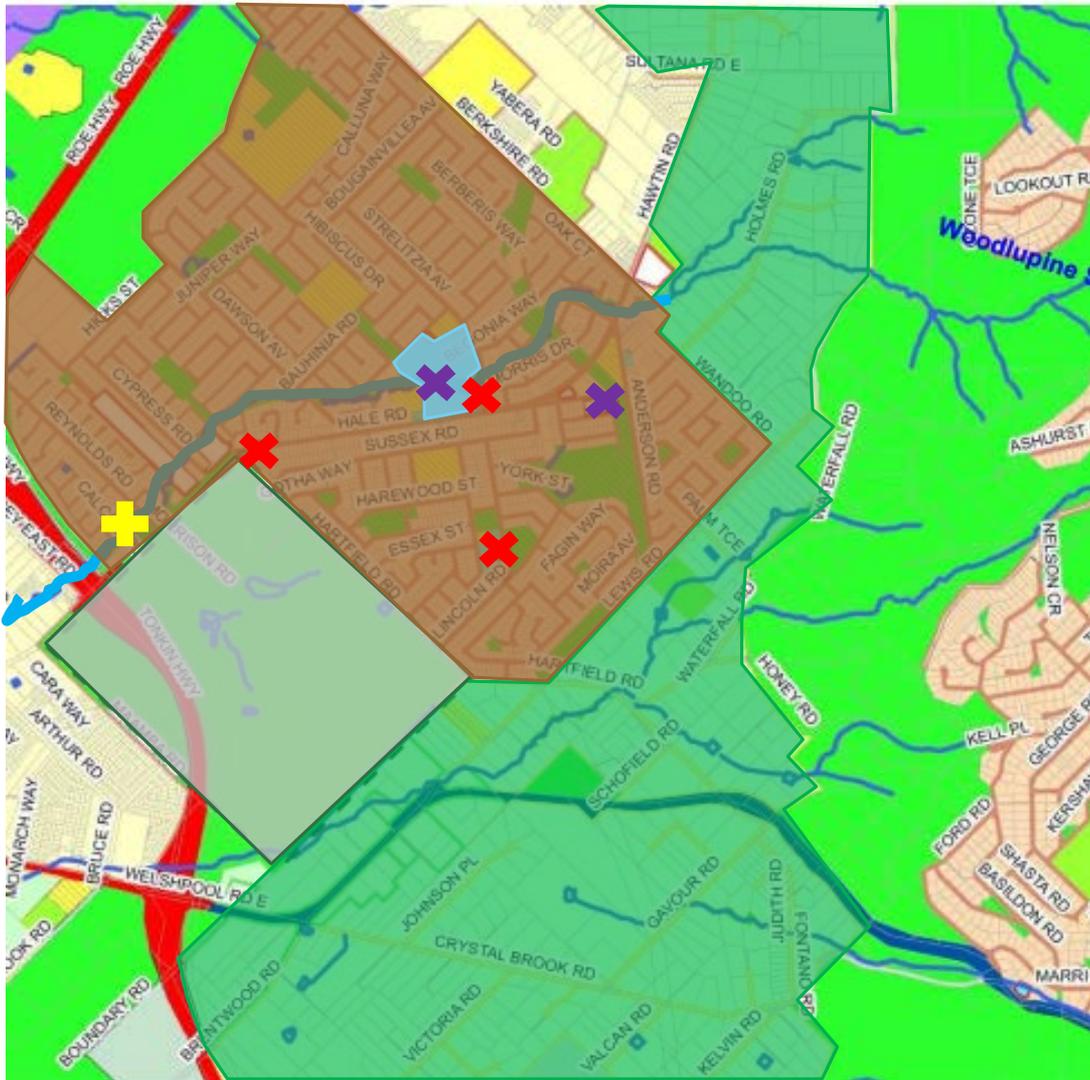
Total Organic Carbon (TOC)

Pesticides: Organic Chlorides (OC) and Organic Phosphates (OP) 

Hydrocarbons: Total Recoverable Hydrocarbons (TRH), BTEX. 

Surfactants: Anionic as MBAS, non-ionic as CTAS. 

Pathogens: Faecal Coliforms and Total Coliforms



Rockwater, 2013

Land Use Survey

Revised Risk Assessment

MAR Hazards	Maximal Risk				Pre-commissioning Residual Risk			
	Human endpoint - irrigation	Environmental endpoint - irrigation	Environmental endpoint - Conservation Wetlands	Environmental endpoint - aquifer	Human endpoint - irrigation	Environmental endpoint - irrigation	Environmental endpoint - Conservation Wetlands	Environmental endpoint - aquifer
1 Pathogens - pathogens present in untreated stormwater. No water will be injected from first flush events.	M	L	L	L	L	L	L	L
2 Inorganic chemicals - none likely present at levels of concern for irrigation.	L	M	L	L	L	L	L	L
3 Salinity and sodicity - stormwater of better quality than groundwater.	L	L	L	L	L	L	L	L
4 Nutrients - nitroegen, phosphorous and organic carbon. None likely present at levels of concern for irrigation.	L	M	L	H	L	L	L	L
5 Organic chemicals - none likely of concern for irrigation.	L	L	L	L	L	L	L	L
6 Turbidity and particulates - not present at levels of concern for irrigation, but may cause clogging (operational risk).	L	M	L	H	L	L	L	L
7 Radionuclides - none likely present at levels of concern for irrigation.	L	L	L	L	L	L	L	L
8 Pressure, flow rates, volumes and groundwater levels. Small scheme in semi-confined aquifer. Injection pressures will need to be monitored and controlled.	N/A	L	L	L	N/A	L	L	L
9 Contaminant migration in fractured rock and karstic aquifers. Not applicable in Bassendean Sand aquifer.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
10 Aquifer dissolution and stability of well and aquitard - predominantly quartz aquifer.	L	L	L	L	L	L	L	L
11 Aquifer and groundwater-dependent ecosystems - aquifer likely confined by Guildford Clay beneath Conservation wetland. No direct connection anticipated.	N/A	L	L	L	N/A	L	L	L
12 Energy and greenhous gas considerations - unknown compared to other options.	N/A	U	N/A	N/A	N/A	U	N/A	N/A

H = high risk; M = moderate risk; L = low risk; N/A = not applicable; U = unknown.

Rockwater, 2015

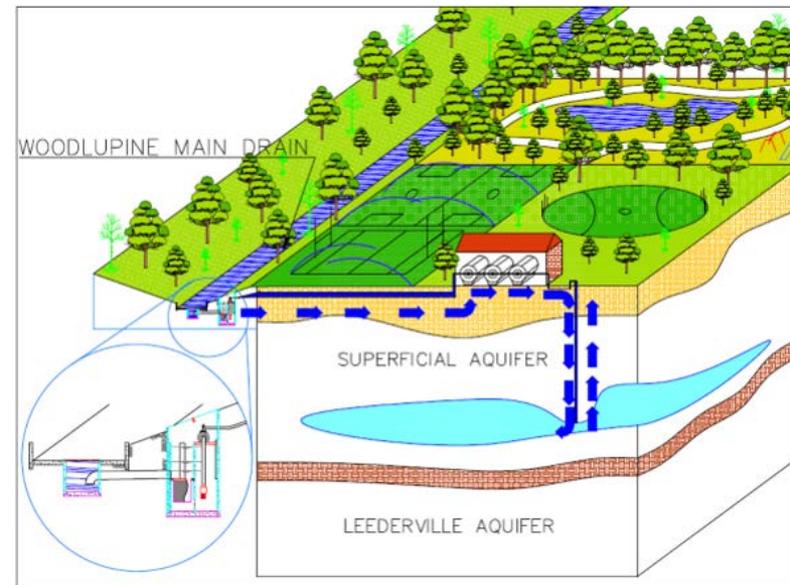
Summary

Stage 1:

- Extra 50 ML/yr for irrigation
- Potential SW source
- MAR feasible
- Infiltration to superficial preferred
- Recharge via bore higher degree of difficulty

Stage 2

- High yield bores
- Clay layer impeding infiltration
- Available stormwater supply up to 230 ML/yr
- Good quality water
- Recharge via bores
- Pre-treatment required



Summary



Stage 3:

- Pre-commissioning trial
- Use existing bore – retrofitted
- Implement monitoring program

Results:

- Low rainfall limited available supply
- Difficulties commissioning specialised equipment
- Water recharged to aquifer at 2 – 4 L/s
- Revised hydrogeological model
- Biological clogging
- Trial to continue with additional treatment

Conclusions

Preliminary results promising

- Aquifer readily accepts water
- Stormwater of high quality

High level of treatment required to manage clogging

- Increases degree of difficulty
- Requires specialised technology
- Requires significant time for commissioning and testing
- High level of operator time and skill

Climate variability requires consideration

- Low rainfall reduces capture opportunities
- Regulation and management flexibility to allow for water banking
- Dedicated injection bore

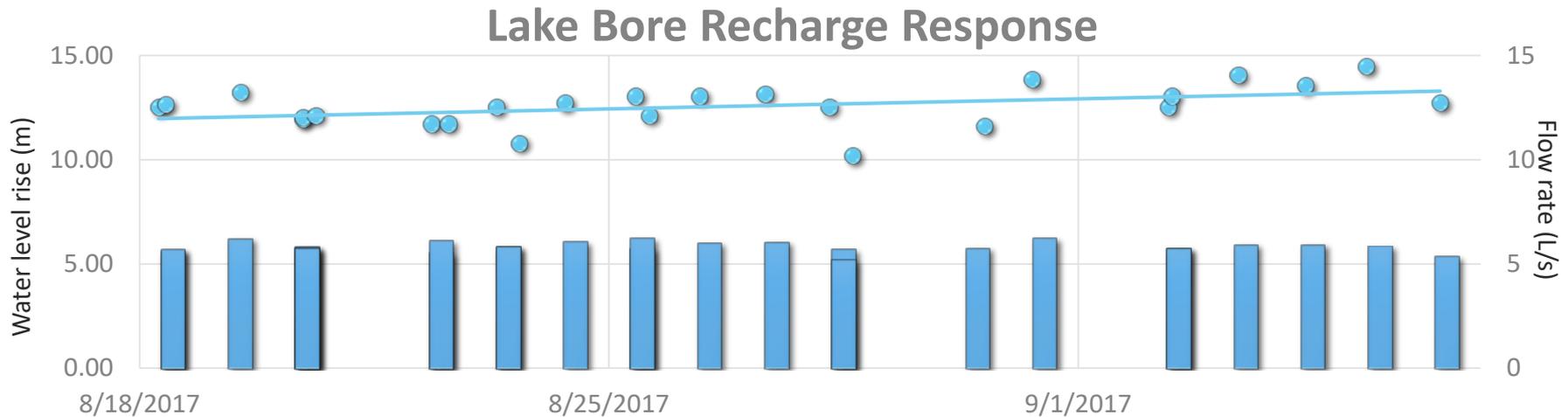
Thank you

Acknowledgments:

- Shire of Kalamunda – Daniel Nelson
- Rockwater team



Addendum – 2017 Trial



- 10,670 kL recharged to Leederville aquifer
- Average injection rate: 5.75 L/s
- Minimal clogging – additional treatment effective
- Likely to progress to operational scheme with dedicated injection bore



Screens after injection – before air-lift

Foothills Water Proofing Strategy

Introduction

The Shire of Kalamunda is located approximately 24km east of Perth, Western Australia with a population of 58,905 (June 2011).

The Shire manages Hartfield Park, a large multi-use reserve that accommodates a variety of sporting and recreation facilities, servicing an extensive area. It also encompasses an area of protected native bushland. The Hartfield Park Master Plan (2010) and Community Facilities Plan (2011) identified the need to increase the amount of irrigated sports fields at Hartfield Park and recommended that alternative water sources be identified to ensure the long term sustainability of the site. A concept was developed to harvest valuable stormwater from the onsite Water Corporation Woodlupine Main Drain. This water would normally be channelled away into the urban water run-off system. The project concept was to extract water from the drain in the winter months and be re-injected into the onsite superficial aquifer under the Department of Water Managed Aquifer Recharge (MAR) policy. The proposed aquifer recharge system would capture and filter the water, re-inject it into the aquifer and increase the Shire license to take water allocation under the Rights in Water and Irrigation Act 1914(RIWI).

A site map identifying the various infrastructure locations as follows:



Hartfield Park MAR Site Map

Project Objective

The fundamental objective of this project is to provide the shire with an alternative and sustainable water source for irrigation purposes into the future. It was determined that the minimum volume of water required to achieve this objective was 50,000kL per annum. The process for determining the viability of a managed aquifer recharge scheme can be summarised into three essential categories:

1. Water demand;
2. Sustainable water source; and
3. Suitable aquifer storage.

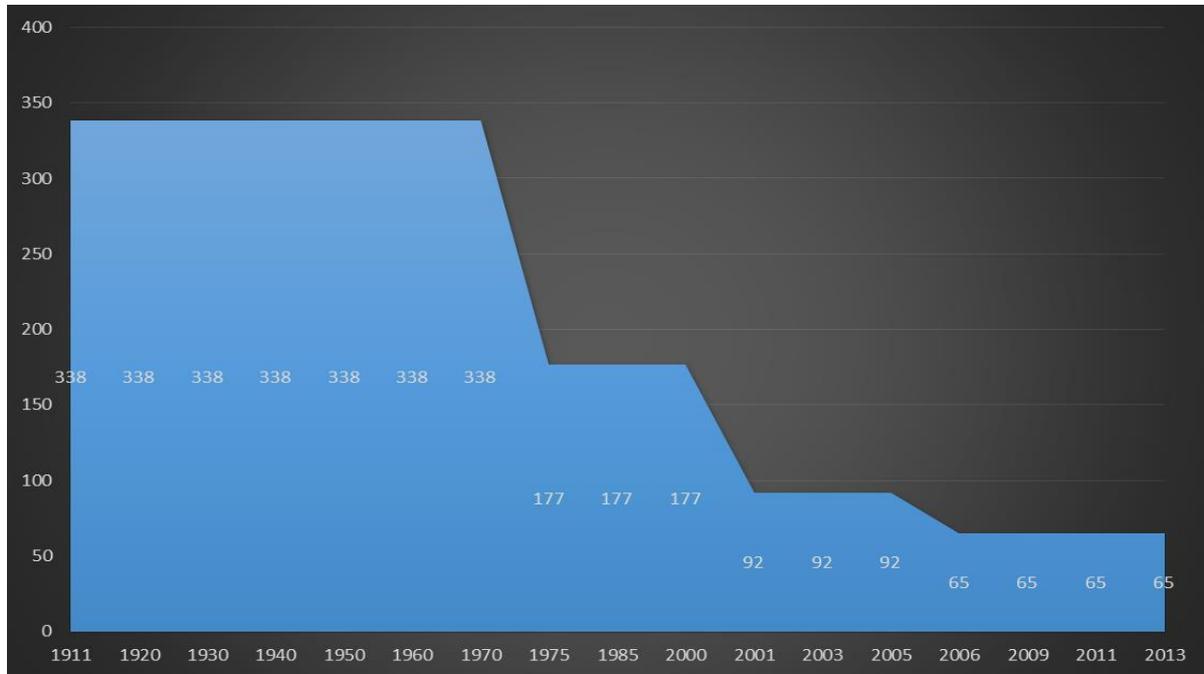
1. Demand

Before undertaking a scheme such as this, it is important to question the need and thereafter, determine if there is a sufficient demand for an alternative water source.

As a result of the Perth's drying climate, growth, water allocation limits and the decline in ground water levels, it was determined that there was sufficient demand for an alternative water source investigation.

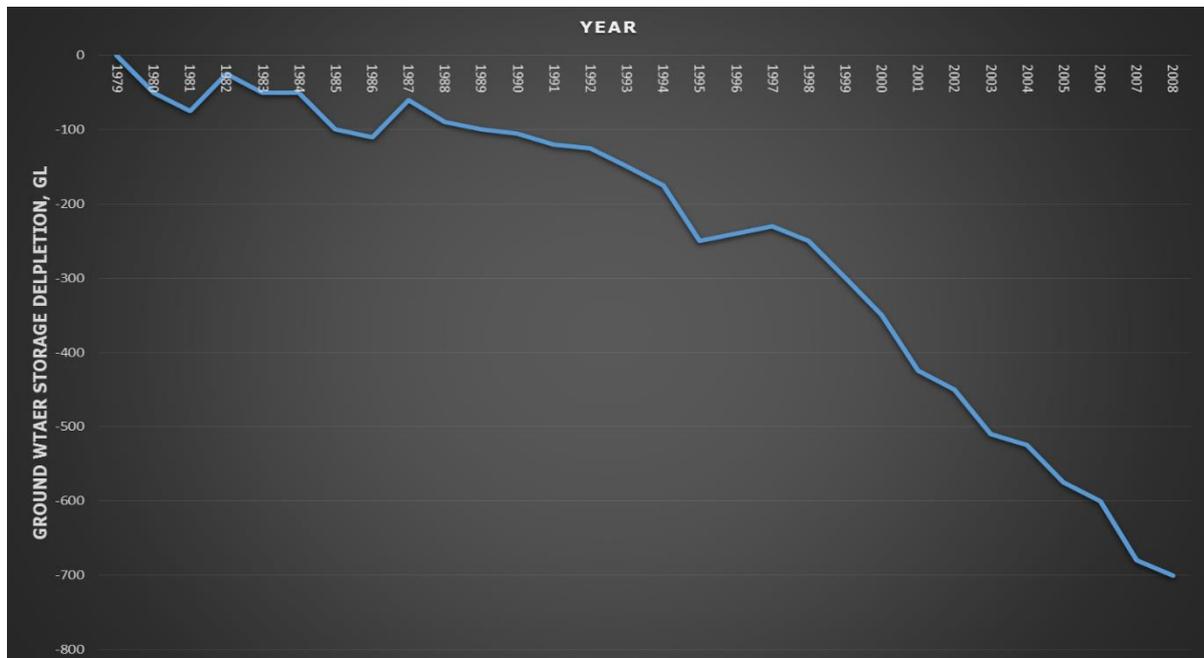
The Perth metropolitan area has a Mediterranean climate with hot dry summers and cool wet winters. The annual long-term average rainfall for Perth is 850mm, but over the last ten-year period the average rainfall has declined to 705mm. The annual potential evaporation is 1,750mm, with evaporation generally exceeding rainfall from September to April.

A drying climate as experienced in Perth is represented by the following Graphs:



Stream Flow Decline

Source: Water Corporation Historical Stream Flow Data.



Ground Water Storage Depletion

Source: Draft Perth-Peel Regional water plan 2010-2030 Department of Water.

The graph titled: *Stream Flow Decline*, represents a substantial decline in the average stream flow run-off between 1911 (average 338GL) and 2013(average 65GL). This has a significant impact on ground water levels as represented in the graph titled: *Ground Water Depletion*. Ground water levels have seen a depletion in storage in the order of 700GL recorded over the last 30-40 years.

The Draft Perth-Peel Regional Water Plan 2010-2030 prepared by the Department of Water identifies the potential groundwater availability.

Groundwater Availability by 2030GL/y

2030 demand scenario	Wet Climate	Median Climate	Dry Climate
Constrained demand(250gl/y)	-37	-74	-107
10% reduction	-12	-49	-82
20% reduction	13	-24	-57

Licensed Private Use Effect of Demand on Groundwater Availability-Perth

Source: Draft Perth-Peel Regional water plan 2010-2030 Department of Water.

The above table indicates even with a 10% reduction on current use and a wet climate, the supply gap will be 12GL (12 Billion litres) by 2030.

As the treated wastewater allocation becomes less available due to the successful use of MAR by the Water Corporation, harvested stormwater will form a significant alternative solution to reducing the supply demand gap.

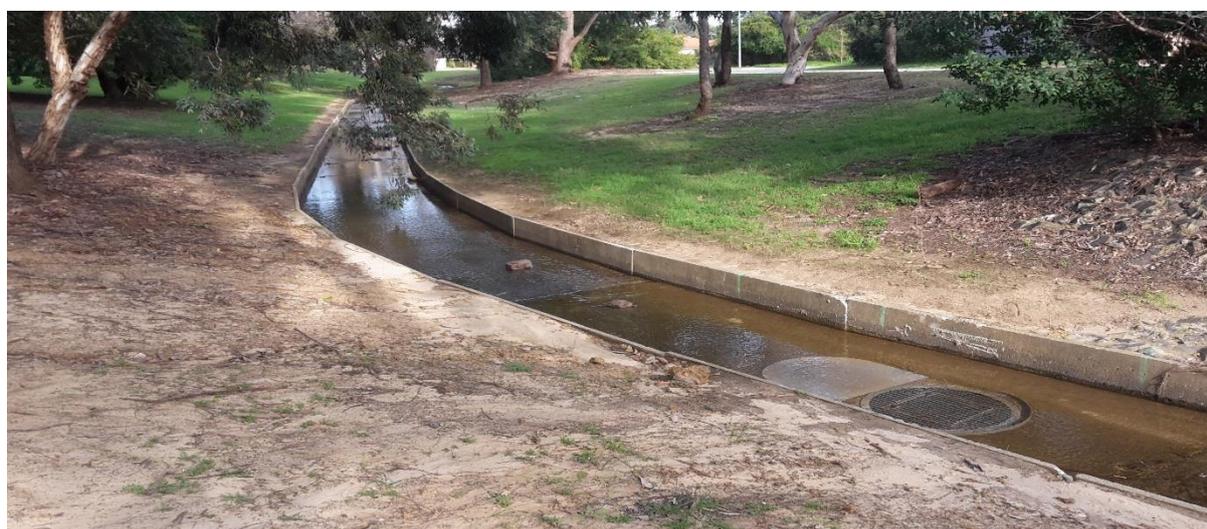
Managed Aquifer Recharge (MAR) provides a means to generate water supplies from sources that may otherwise be wasted. It can provide environmental, social, and economic benefits. MAR involves recharging an aquifer under controlled conditions to store the water for later abstraction, or to achieve environmental benefits, (source: MAR operational policy Department of Water).

2. Sustainable Water Source

Question: "Is there an adequate source of water available for allocation to recharge?"

A concept was developed to harvest valuable stormwater from the onsite Water Corporation Woodlupine Main Drain. This water would normally be channelled away into the urban water run-off system.

The stream takes its source in the hills near Kalamunda, west of Canning Road, with some small tributaries starting on the flanks of the Darling Scarp. The stream flows westerly via the main drain towards the Canning River, with the majority of the flow occurring between June and November each year.



Woodlupine Main Drain

The drain flow data indicates that the majority of flow occurs from June to October, generally peaking in July and August at approximately 12,000kL/d or 140L/sec. There is a declining trend apparent in the data that follows the reducing rainfall trend; with the long-term average annual flow being 1.5GL/annum compared with 1.3 GL/annum for the last ten years. From the available data, the average volume of flow over the proposed extraction months is calculated to be 1.4GL using the long-term average, and 1.1GL/annum using the previous ten-year average. If a volume of 357,500kL was harvested for use in the MAR project, this volume would be enough to increase the Hartfield Park groundwater licences by up to 100%, (assuming a 1:1 infiltration/extraction ratio). This would represent 26 % or 31 % of the flow in the drain during June to October, using the long-term and the previous ten-year annual average flow volumes, respectively. Based on the site flow data, it was calculated that the proposed recharge volume will exceed the project objective of 50,000k/L.

Drain flow as measured 300m downstream of the Hartfield Park site, has been recorded since 1985 with monthly average flow data presented in as follows:

Month	Long-term Monthly Average		10-yr Monthly Average	
	kL/d	Total kL	KL/d	Total kL
Jan	155	4,809	31	946
Feb	229	6,494	32	913
Mar	96	2,984	113	3506
Apr	429	12,860	345	19340
May	1,577	48,897	1,550	48038
June	6,551	196,906	4,736	142,069
July	11,564	345,694	9,500	294,502
Aug	12,792	382,397	11,053	342,658
Sept	5,311	287,848	8,081	242,441
Oct	2,140	164,634	3,912	121,258
Nov	2,140	64,208	18,999	56,969
Dec	268	8,008	240	7,450
Annual	4,226	1,525,739	3,483	1,280,090

Woodlupine Main Drain Average Monthly Flow Rates recorded since 1985

The water quality samples indicate that the water is very fresh (<250 mg/L TDS), moderately alkaline, and generally contains relatively low concentrations of metals and nutrients. Total suspended solids (TSS) and turbidity can be high and are variable. Sampling also indicates some microbial activity within the main drain water, which at times appears to be relatively high.

Following main drain flow calculations and water quality sampling, it was determined that there is adequate volume for a MAR scheme, even in a very dry year.

3. Suitable Aquifer Storage

Question: "Is there a suitable aquifer for storage and recovery of the required volume?"

A preliminary feasibility study found the proposal to have reasonable potential for success and further investigation was recommended to confirm the suitability of the site and water source for the implementation of a MAR scheme.

The initial proposed injection method involved the use of infiltration ponds as these were considered to be cheaper, less sophisticated to operate and potentially less prone to clogging than injection bore systems. The test-drilling results have shown that Bassendean Sands at Hartfield Park form a thin layer over an impermeable layer of Guildford Clay. The clay extends over most of the site and lies between the ground surface and the groundwater table. As a result, utilising an infiltration basin or infiltration galleries were deemed infeasible, as this would be similar to trying to fill a cup that is already full. However, the results of further investigation, which included on-site drilling, aquifer testing and numerical groundwater modelling, indicated that MAR to the superficial aquifer is likely to be a viable alternative through the use of injection bores to recharge the stormwater direct to the aquifer. Preliminary calculations indicate that between 115,000kL and 230,000kL of water per annum could be potentially recharged for future use, far exceeding the project objective of 50,000kL.

The flowing table summarises the viability outcomes of the three essential categories to the project objective.

1. Is there a sufficient demand for water?	Yes - Increasing demand for water at Hartfield Park due to a drying climate and the proposed increase in irrigated sporting fields.
2. Is there an adequate source of water available for allocation to recharge?	Yes - Woodlupine Main Drain contains an adequate supply of water, even in very dry years.
3. Is there a suitable aquifer for storage and recovery of the required volume?	Yes - Numerical groundwater modelling indicates that MAR to the superficial aquifer is likely to be viable using injection bores to recharge the stormwater direct to the aquifer.

Viability Assessment Criteria Table

After reviewing the assessment criteria, the project was considered viable and a MAR trial was commissioned and operated throughout the 2015 winter in order to confirm the feasibility of the scheme.

Implementation of the Trial

Prior to implementing the trial, the Shire's Consulting Hydrologist developed a Water Resource Management Operating Strategy for the Stormwater Harvesting and Managed Aquifer Recharge Trial. The (WRMOS), specified the following:

1. Management Objectives;
2. Operating Rules;
3. Monitoring and Reporting;
4. Environmental Impact Management;
5. Contingency plan; and
6. Water use Efficiency.

The WRMOS was developed in order to obtain the necessary water licenses to commence the trial.

The Maximal and Residual Risk Assessment Summary for Hartfield Park MAR was used to define the scope of works, with a risk mitigation strategy determining the infrastructure required to undertake the trial.

Prior to injection of the stormwater into the aquifer, the water was filtered to a very high standard to prevent bore and aquifer clogging through introduction of suspended solids. The particle size distribution analysis on the main drain water indicated that 90% or more of the particles in the water were <10 micron in diameter, this further indicated that very low concentrations of very small diameter size particles can still cause clogging to the degree that operational management is required. Therefore, it was determined that the stormwater be filtered to 2 micron to prevent bore clogging and mitigate the necessity for installation of a dedicated down-hole backwashing system.

The Shire developed a scope of works with the fundamental objective to procure a low maintenance, self-backwashing filter package which can filter water to 2 micron. An AMIAD multi stage filter package consisting of the following. An AMIAD AMF 370k filter with Timex separator and SAF filter.

The Timex separator filters the water to 70 micron, followed by the SAF filter to 50 micron and finally the AMIAD AMF370k to 2 micron.

This photograph illustrates the filtration packaged prior to being enclosed by the filtration building.



Filtration Unit Prior to Building Enclosure

The commissioned filtration unit periodically shuts down for backwashing. As a result, a "slow opening" bore injection valve needed to be engineered in order to ensure air is not being injected to the aquifer, given entrained air can have a negative effect on the water flow through the aquifer due to, air-fouling and bio-fouling.

An automated flow valve in the injection bore was required, with the valve needing to have the ability to go into a standby mode during back flush events. The injection valve also had to be capable of monitoring and controlling the following;

- Headwork's pressure;
- Pressure in bore while injecting;
- Bore water level;
- Water flow; and
- Water temperature.

It was essential that system continuity be developed between the infrastructure located at the Woodlupine main drain, the filtration unit and the injection valve all of which were procured from three separate suppliers. Also, this infrastructure had to be user friendly, compatible and easily maintained technology which could not to be purchased as a package off the shelf. As a consequence, the Shire had to work diligently with irrigation and filtration experts, engineers and hydrologists to develop this system.

MAR Trial Results

The Shire had to overcome several engineering challenges in the design, construction and commissioning of the infrastructure necessary to meet the requirements outlined by the WRMOS and the Water License Conditions.

The Shire has satisfied the Department of Water's MAR policy by determining through aquifer testing and numerical groundwater modelling, that the superficial aquifer located at Hartfield Park is viable for MAR.

Water was extracted intermittently from the Woodlupine Main Drain at a transfer station located on the adjacent reserve, from late-July to August 2015. The water was filtered and recharged to the aquifer using an existing production bore at Hartfield's Parks (Lakes Bore), retrofitted for the purpose. Water level response was monitored in the Lakes Bore and five monitoring bores located in the vicinity of the lakes bore, and water quality sampling was undertaken throughout the trial. Due to a record low water run off year as a result of late and low levels of winter rainfall, the amount of flow in the main drain suitable for recharge was significantly lower than the expected average flow. The Shire also experienced technical difficulties associated with commissioning the specialised equipment for the trial and as a result, the recharge volume into the aquifer was less than anticipated and this was characterised by intermittent injection. It is therefore considered that while the requirements of the trial have been achieved with the injection of 4,400kL of filtered stormwater, the trial period will need to be continued into the next winter to fully prove the concept.

There are limited examples of managed aquifer recharge projects in Western Australia and as such, this technology requires bespoke design, innovation and research.

Lessons Learnt

The fundamental lessons learnt as a result of the trial, are as follows:

1. It is critical that during the scheduling and planning phase, significant time is allocated for the commissioning of specialised infrastructure;
2. Extreme climate conditions must be including in your risk modelling; and
3. The approval process and /or the hydrological feasibility and viability assessment requires the allocation of appropriate resources and time.

The Shire, through working with its Hydrologist and the Department of Water, has provided invaluable data and process for MAR using stormwater in Western Australia.

The Spectacles wetlands

The Spectacles is 360 hectares of natural bush and wetland, and is a part of the chain of wetlands that make up the Beeliar Regional Park. It is the largest fresh-water lake in the town of Kwinana and is situated between the Ramsar wetland areas of Thompsons Lake and the Peel-Yalgorup system. The Spectacles wetlands has one of the largest stands of Paper-bark woodland in the metropolitan area and Birds Australia have identified 87 species of water birds, birds of prey and woodland birds. The wetlands are a breeding ground for the Rufus Night Heron and the Swamp Harrier. There are a number of land animals including; bandicoots, snakes, occasional wallabies, possums and bats.

The area is a significant site for Aboriginal people being a part of the Wajuk peoples traditional land situated in the greater Nyoongar language group that encompasses the south west of Australia. The Spectacles is on the ancient trade route that follows the fresh water lakes system connecting the people of the Murray and Swan Rivers and has cultural significance as a ceremonial, camping and food gathering site.

<http://www.bushlandperth.org.au/member-groups/4-south-of-the-river/60-friends-of-the-spectacles>

The Spectacles wetlands, consisting of Spectacles north and Spectacles south, are Environmental protection policy lakes, are part of the Beeliar Regional Park, are listed on the Directory of important wetlands in Australia (Environment Australia, 2001) and lie within Bush forever site 269. The 349 ha area contains significant flora *Dodonaea hackettiana*, a number of significant mammal and reptile species and provides an important waterfowl breeding site.

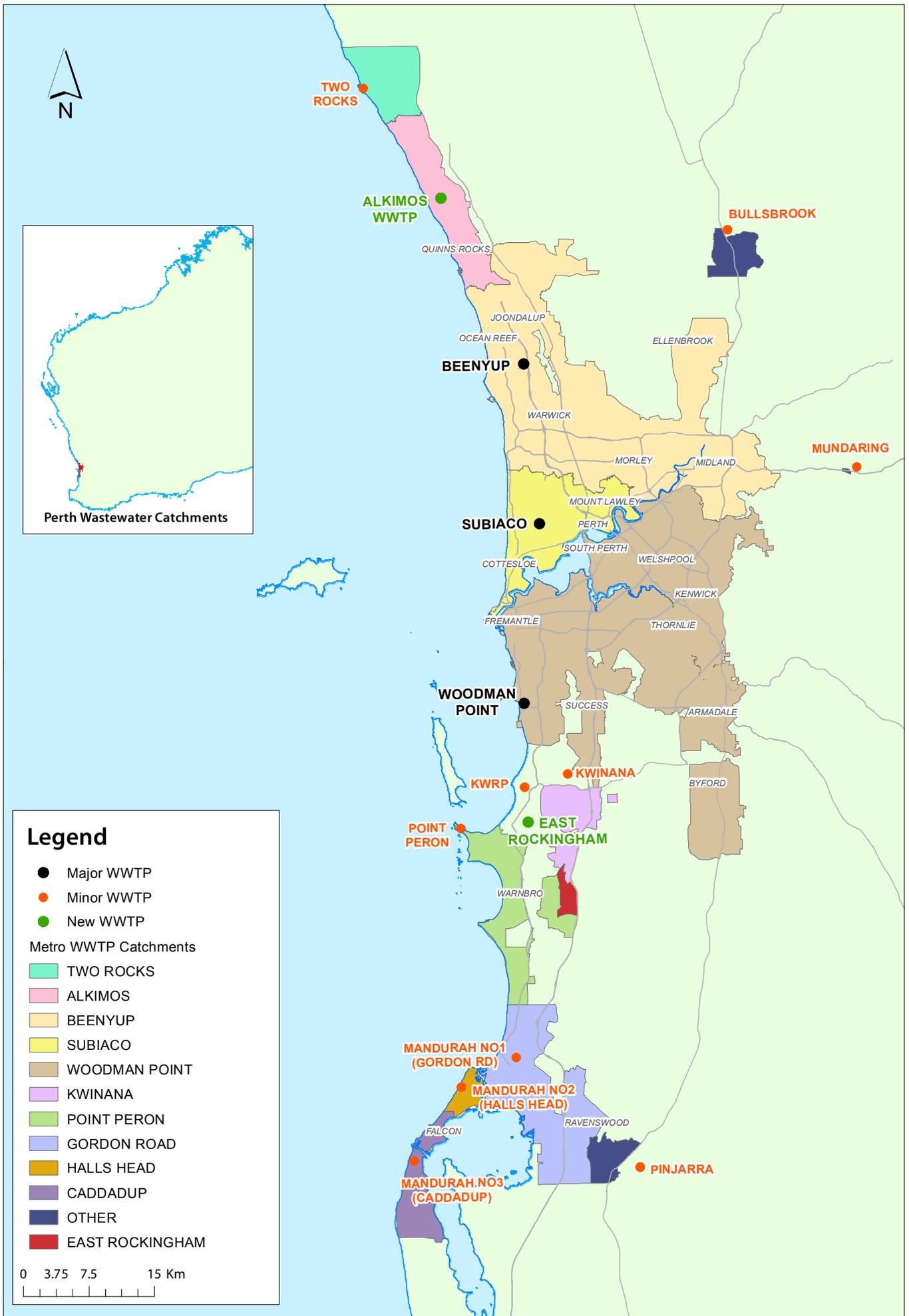
A comprehensive hydrogeological and nutrient balance investigation was undertaken by the Waters and Rivers Commission in 1997 (Shams, 1997), with key findings as follows.

- The northern extent of the Peel main drain entering the wetlands is often not hydraulically connected to groundwater due to clayey sediments.
- While the general flow direction of groundwater is west-south west, a small groundwater mound created by the Kwinana wastewater treatment plant to the west of the wetlands was thought to cause the groundwater locally to flow east. This was, in turn, thought to transport contaminants from the Kwinana wastewater treatment plant to Spectacles north, though subsequent hydrological investigations reported that infiltrating effluent at the Kwinana wastewater treatment plant does not reach the wetlands (Woodward Clyde, 2000).
- The Peel main drain contributes approximately 48 per cent of the water entering the Spectacles, while the remainder is from groundwater.

Bushland condition scores, using the Bush forever scale, were given to Spectacles north and Spectacles south as part of the ecological water requirements study conducted by Ecoscape (2007). Vegetation within the four survey plots of Spectacles north were rated excellent to pristine, while the six survey plots of Spectacles south were rated good to pristine. The most vulnerable of the dominant/key wetland species recorded by Ecoscape on the Spectacles north and south transects were *Baumea articulata* and *Juncus pallidus* respectively.

It is concluded by Parsons Brinkerhoff (2004) that the Spectacles wetlands play an important role in managing water quality within this catchment, having an impact on total nitrogen, total phosphorous and total suspended solids. However, the assimilative capacity of these wetlands is finite and therefore the focus of this drainage and water management plan in the vicinity of the Spectacles wetlands is on preventing future stormwater contamination (both in terms of pollutant loads and concentrations).

https://www.water.wa.gov.au/data/assets/pdf_file/0018/1746/91068.pdf



Major wastewater treatment plant catchment boundaries

Perth Wastewater

Ocean Rd Reserve

CADDADUP RE-USE MAR PROJECT



Groundwater Re-use – Recovery of TWW



Esperance WWTP – recovery bores (Rockwater)

- Water Corporation responsible for treatment and disposal of wastewater
- Infiltration Licenced by DER
 - Max allowable volume for infiltration
 - Water quality requirements and monitoring
- Recovery bores » Fit for purpose water supply
 - Irrigation
 - Industry
- DoW (now DWER) » regulate extraction using MAR policy

Western Australia Experience

City of Mandurah, Water Corporation, CSIRO



Indirect re-use of treated wastewater for irrigation of public open space

Halls Head Indirect Water Reuse Project: 2002

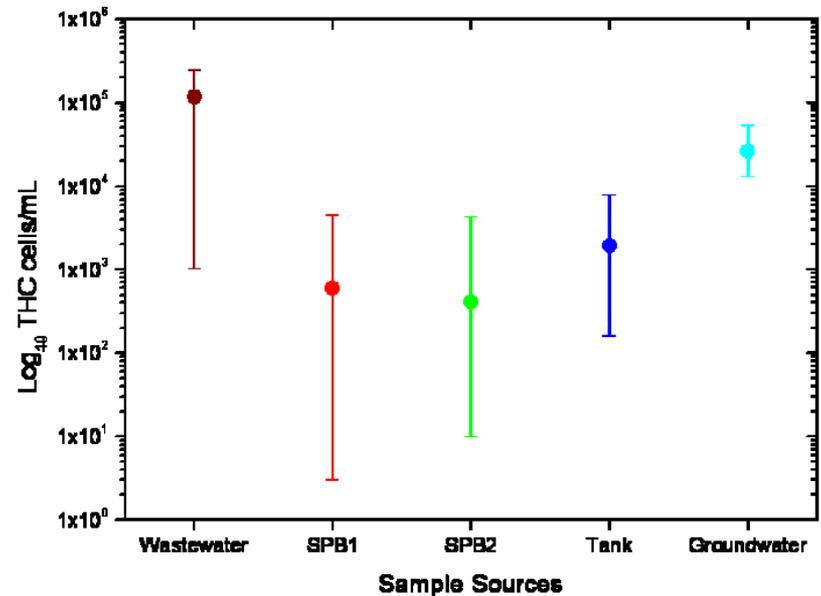
- Research and development site - assessed potential for TWW re-use using aquifer as natural treatment
- System monitored over 2 years
- Assessed yield, aquifer parameters, flow characteristics
 - 840 ML infiltrated over 20 months
 - 122 ML recovered same period: 80% of which infiltrated TWW
 - Cavernous limestone: highly heterogeneous, tidal influence
 - Flow 2.5 m/d: 24 days to nearest production bore at 60 m



Toze, Hanna, Smith and Hick. CSIRO Report to Water Corporation October 2002

Halls Head Indirect Water Reuse Project: 2002 (cont.)

- Health parameters tested:
 - Bacteria
 - Viruses
 - Heavy metals
- *E coli* in recovered water <1 cell/100 ml
- No pathogens detected in groundwater or recovered water (although present in TWW)
- Removal due to action of indigenous groundwater microorganisms
- Detected heavy metals (Zn and Pb) below drinking water quality guidelines
- Nutrients (TN, TP, TOC) degraded or attenuated in aquifer
- Salinity of GW improved and more suitable for irrigation



Average, maximum and minimum total heterotrophic count bacterial (Toze et al 2002)

Halls Head Indirect Water Reuse Project: 2002 (cont.)

Conclusions

- Water recovered for indirect re-use suitable for irrigation purposes with negligible health or environmental risks

Recommendations:

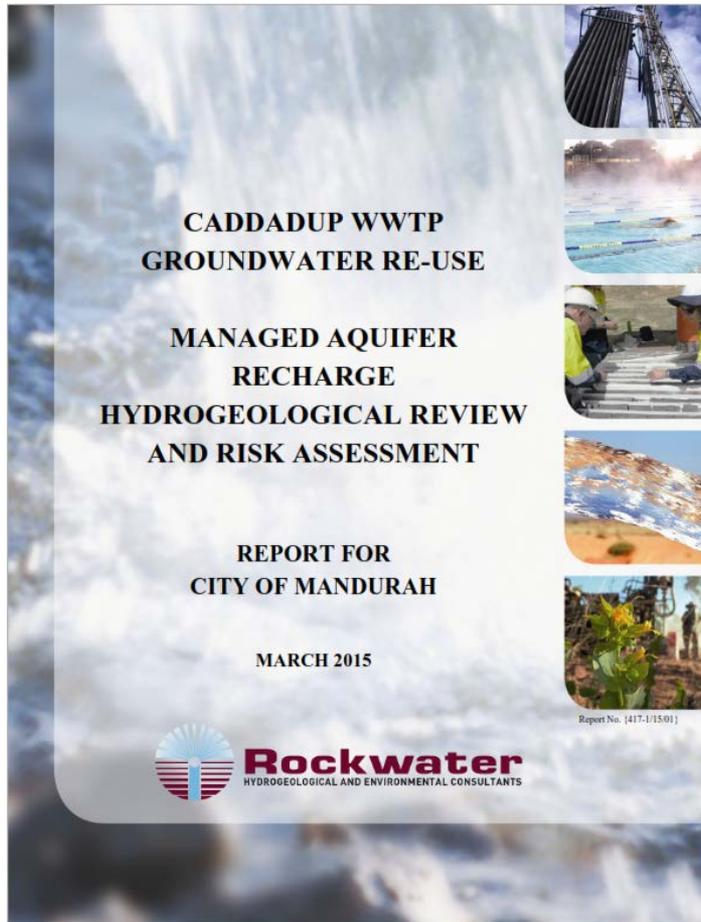
- Develop re-use protocol with relevant regulators outlining requirements for indirect re-use in WA
 - WA MAR Guidelines
- Prior to development of re-use scheme conduct hydrogeological assessment to ensure optimal placement of recovery bores and confirm low risk
 - Today's case study
- Conduct community consultation to obtain stakeholder approval



Solution channels evident in Tamala Limestone approx. 100 m south west of infiltration ponds (Toze et al 2002)

Caddadup WWTP Re-use

Hydrogeological Review and Risk Assessment

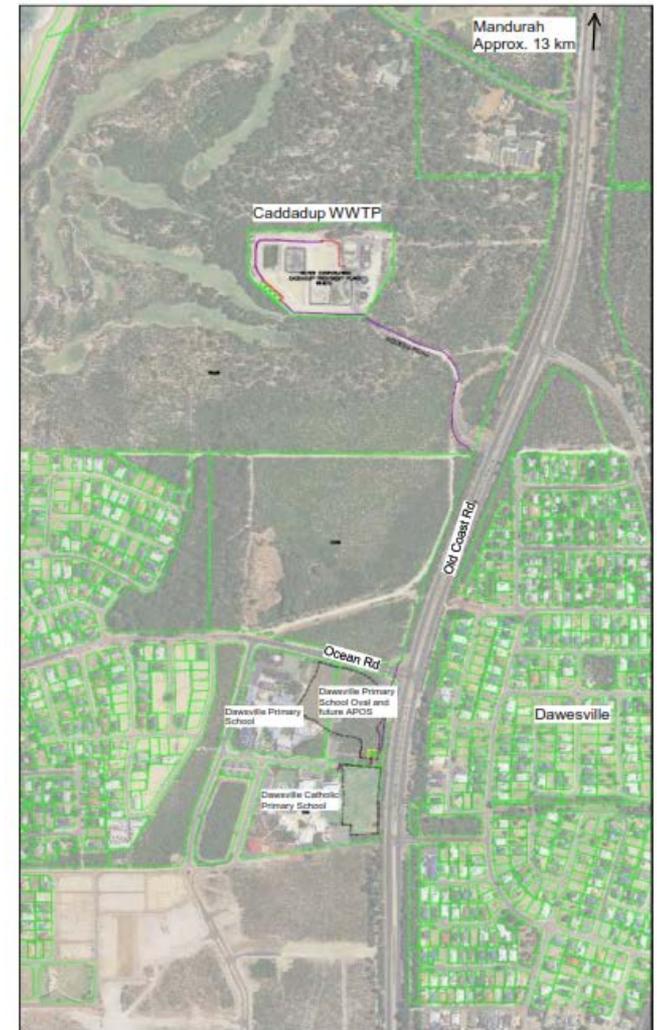


Acknowledgments:
Phil Wharton, Rockwater
Dale Robinson and John Harris, City of
Mandurah

Introduction

2015 Indirect Re-use Project Proposed

- Caddadup Wastewater Treatment Plant (WWTP)
- Installation of recovery bores to capture treated wastewater (TWW)
 - Water recovered over and above GW allocation
- Alternate water supply for Ocean Rd Reserve
 - 3 ha of public open space
 - 1.3 km pipeline
 - Require 120,000 kL/annum
- DWER (then DoW) Regulating as MAR
 - Operational Policy 1.01 Managed Aquifer Recharge in Western Australia (2011)
- Stage 1 Prefeasibility Assessment >> likely viable subject to appropriate bore design and pumping rates to minimise risk of up-coning of saline water



location.tif

Approx. 0 100 200 m

Image provided by City of Mandurah

Setting

Caddadup WWTP located about 13 km south of Mandurah, WA.

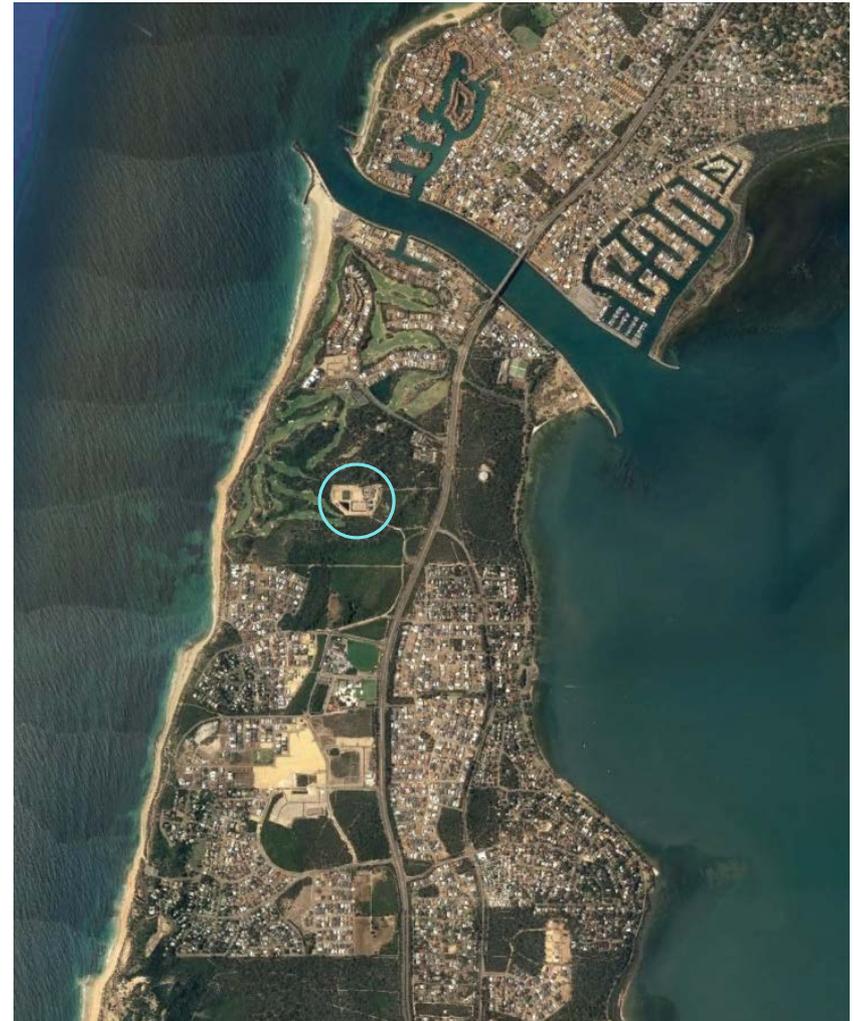
Mediterranean type climate

- Long hot summers
- Cool wet winters

Lies on thin strip of land between Indian Ocean (~650 m) and Peel-Harvey Estuary (~900 m)

Low coastal dunes: ~5 to 10 m AHD

Surrounded by bushland with golf course to west



Hydrogeology

Quaternary Tamala Limestone – variably cemented limestone and medium- to coarse-grained sand

Unconformably overlies Cretaceous Leederville Formation – interbedded sandstone, siltstone and shale at ~35 m depth

Low-relief, elongated groundwater mound in Tamala Limestone beneath the peninsular

Highly permeable, unconfined aquifer

Groundwater flows under low gradient to coast in west and Harvey Estuary in east

Natural recharge via rainfall infiltration

Infiltration since 1994 with rates increasing from ~120 kL/d (1998) to 1600 kL/d (2014)

Thickness of groundwater with salinity <1000 mg/L increased from <5 m (1996) to ~10 m (2014)

Elevated TN (up to 40 mg/L) but declining with improved WW treatment

Regulatory Requirements

Caddadup WWTP licenced under Environmental Protection Act 1986. Regular monitoring and reporting to DER (now DWER)

- Water Corporation Licence

Recycled Water Quality Management Plan required by and provided to Department of Health

- City of Mandurah approval

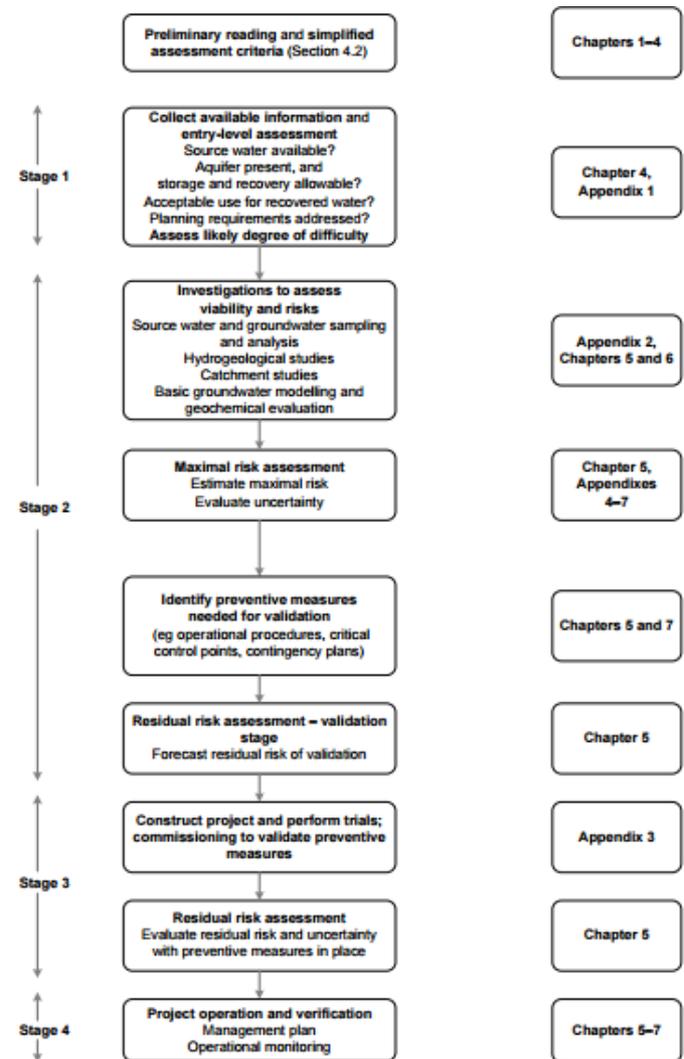
Regulated as MAR site by DoW (now DWER) under WA MAR Guidelines utilising National Quality Management Strategy, Australian Guidelines for Water Recycling: managing Health and Environmental Risk (Phase 2) Managed Aquifer Recharge

- City of Mandurah – showing Water Corporation approval
- Initial conditions included infiltration compliance – however removed due cross over of responsibility between organisations

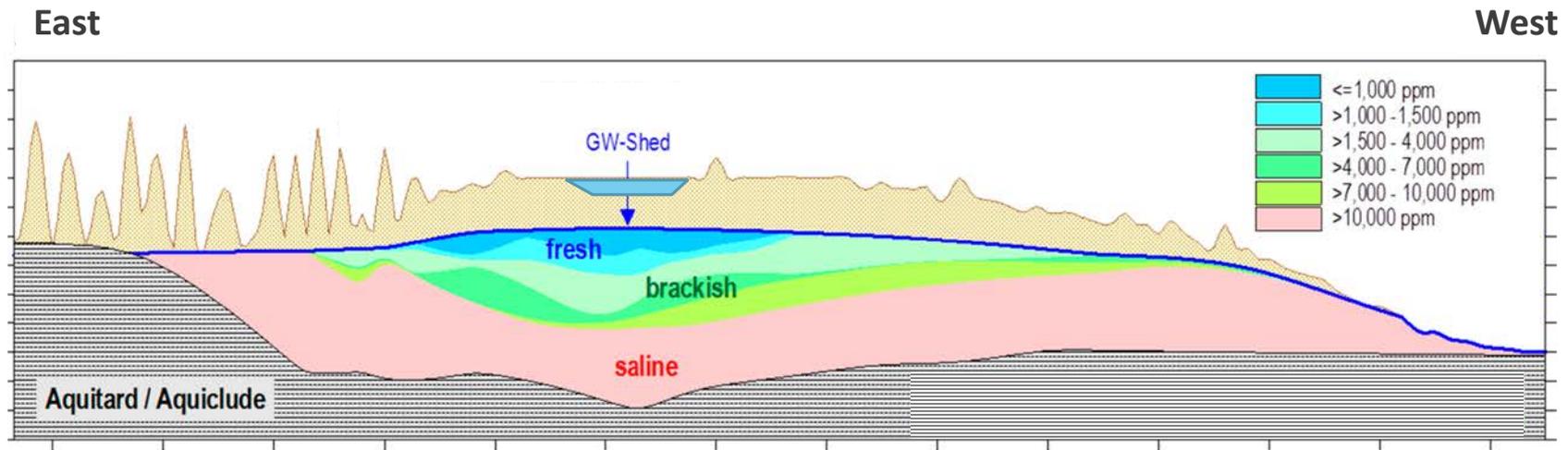
Where this investigation fits under the Australian MAR Guidelines

Stage 1 completed –

- Key risks associated with project identified:
 - Potential GW salinity > end use requirements
- Preventative measure proposed:
 - Carefully designed and constructed recovery bores
 - Low pumping yields to prevent up-coning
- DoW consulted and licence with conditions provided.
- Drilling and aquifer testing program prepared and costed:



Stage 2 – Investigations and Risk Assessment



Representative cross-section, for illustrative purposes only. (Modified from Stuyfzand et al 2017)

Drilling and Aquifer Testing Program Objectives

- Define extent and depth of fresh water lens
- Confirm geology and define aquifer thickness
- Measure aquifer permeability and storativity
- Determine sustainable pumping rates
- Confirm low risk from pathogens

Drilling and Aquifer Testing Program

Operational TWW infiltration site:

- Infiltrating 20 years
- Fresh water lens developed and thickened
- Infiltration rates: up to 1.6 ML/d

- Series of existing monitoring bores with long-term groundwater level and water quality data
- Install a set of nested SWIM (salt water interface monitoring) bores
- Install test production bore



Surfer\15-01\bore locations.srf

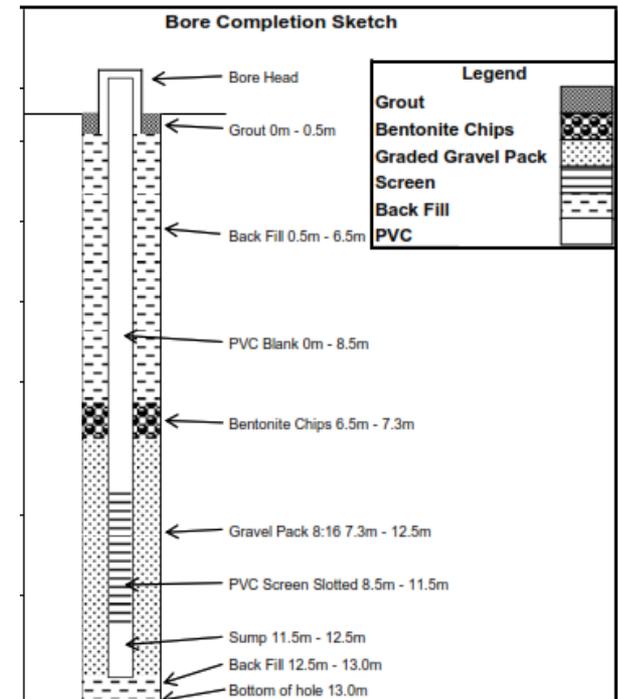
Test Drilling

Set of nested SWIM bores drilled and constructed:

- 5 to 15 m from test production bore
- Monitors change to salinity at various depths in response to pumping
- Completed with 50 mm PVC to allow groundwater sampling

Test production bore drilled and constructed:

- Small diameter – low yield bore
- Screens set within freshwater lens
- Sump to allow pump to be set deeper to maximise available drawdown in shallow bore
- Yield 130 kL/d
- Hydraulic conductivity between 215 and 380 m/d



J&S Drilling – Bore construction log



Water Quality Results

Analyte grouping/Analyte	Units	LOR	19/12/2014	Irrigation Guideline Value
Field Parameters				
pH Value	pH Unit	0.1	7.5	6 - 8.5
Electrical Conductivity @ 25°C	µS/cm	1	814	1,000
Metals and Metalloids				
Aluminium	mg/L	0.01		5
Arsenic	mg/L	0.001	0.003	0.1
Boron	mg/L	0.01	0.77	
Beryllium	mg/L	0.01	<0.01	
Cadmium	mg/L	0.002	<0.002	0.01
Chromium	mg/L	0.01	<0.01	0.1
Copper	mg/L	0.01	<0.01	0.2
Lead	mg/L	0.01	<0.01	2
Zinc	mg/L	0.01	<0.01	2
Iron ¹	mg/L	0.05	0.03	10 (0.2)
Nutrients				
Ammonia as N	mg/L	0.02	0.08	
Nitrate as N	mg/L	0.01	0.95	
Nitrite + Nitrate as N	mg/L	0.01	1.0	
Total Nitrogen as N	mg/L	0.1	1.4	
Total Phosphorus as P ¹	mg/L	0.01	0.02	12 (0.05)

Comprehensive Assessment:

Against Irrigation Guideline Values (ANZECC 2000)

- Salinity and SAR ✓
- Metals ✓
- Nutrients ✓
- Chemicals of Concern
 - Pesticides ✓
 - Herbicides ✓
- *E Coli* <10 MPN/100mL

Very good quality for Irrigation

Risk Assessment Analysis

Key Risks Previously Identified:

- Pathogens (TWW)
- Groundwater salinity increase due to up-coning

Investigations Stage 2 Showed:

- Pathogens low risk >> not measured in recovered water
- SWIM bores >> Fresh water from water table (5 m depth) to base of aquifer (~15 m depth)
- Pumping at 1.5 L/s (130 kL/d) >> minimal drawdown
- Higher transmissivity (permeability) than previously assumed

Results support Stage 1 conclusion 120000 kL/yr achievable

Summary of Maximal and Residual Risk Assessment

	Re-use Hazards	Maximal Risk		Pilot Trial Residual Risk	
		Human endpoint - irrigation	Environmental endpoint - irrigation	Human endpoint - irrigation	Environmental endpoint - irrigation
1	Pathogens - pathogens present in infiltrated wastewater, shown to be removed in aquifer.	H	L	L	L
2	Inorganic chemicals - none likely present at levels of concern for irrigation.	L	L	L	L
3	Salinity and sodicity - fresh water lens created by infiltration. Saline up-coning potential.	N/A	M	N/A	L
4	Nutrients - nitrogen, phosphorous and organic carbon. None present at levels of concern for irrigation.	L	L	L	L
5	Organic chemicals - none likely of concern for irrigation.	L	L	L	L
6	Turbidity and particulates - not present at levels of concern for irrigation.	L	L	L	L
7	Radionuclides - none likely present at levels of concern for irrigation.	L	L	L	L
8	Pressure, flow rates, volumes and groundwater levels. Risk associated with recharge, licenced by DER.	N/A	N/A	N/A	N/A
9	Contaminant migration in fractured rock and karstic aquifers. While karstic features may be present, no evidence of contamination to date.	M	L	L	L
10	Aquifer dissolution and stability of well and aquitard - Risk associated with recharge, licenced by DER.	N/A	N/A	N/A	N/A
11	Aquifer and groundwater-dependent ecosystems - risk mainly associated with recharge, licenced by DER. Low risk associated with proposed pumping.	L	L	L	L
12	Energy and greenhouse gas considerations - unknown compared to other options.	N/A	U	N/A	U

Stage 2 – Results



- Investigations assessing indirect re-use of TWW for irrigation indicated the scheme likely to be viable
- Any risks identified readily mitigated through:
 - Appropriate bore design and low production rates
 - Site access controls and operational water quality monitoring
- Implementation of operational re-use scheme (Stage 3) recommended

Stage 3 – Construction and Commissioning

- Construct four additional recovery bores to abstract 120000 kL/annum
- DoW requirement to define “MAR Infiltration Zone”
 - Zone of usable fresh water
 - $GWL \uparrow > 0.4 \text{ m}$
 - WQ from drilling and WC monitoring
 - Two zones, low and higher risk

Development of MAR Infiltration Zone Boundaries



Operational Management Plan and Monitoring Program

- Operating Strategy developed to DWER Guidelines
- Monitoring program specified
 - Production rates and total volume pumped
 - Continuous GWL monitoring in SWIM bores
 - Periodic GWL monitoring in production bores
 - Water quality monitoring:
 - Salinity every six months and major components annually from production bores, storage tank and SWIM bores
 - Annual E Coli sampling from production bores
 - Continuous EC, pH and Temp in SWIM bores
 - Water Corp. data to be incorporated

Summary and Conclusions

Alternative Water Supply Required for Ocean Rd Reserve

- 3 ha irrigated open space
- 120000 kL/annum required

Stage 2 Viability Assessment Undertaken

- Confirmed Stage 1 conclusions
- Indicated risks of salinisation and water quality could be adequately managed

Stage 3 Operations Planned and Implemented



Thank
you



Karen Johnston – Managed Recharge

Level 24 | 77 St Georges Terrace | PERTH WA 6000

0407 198 398 | karen.johnston@managedrecharge.com.au |

www.managedrecharge.com.au

OCEAN ROAD RECREATION AREA: MANAGED AQUIFER RECHARGE WASTEWATER REUSE

*Terry Blanchard
Manager Technical Services
City of Mandurah WA*

Introduction

This Ocean Road Recreation Area project was borne out of necessity to provide recreational facilities for an area devoid of sporting opportunities for the residents south of the Dawesville Channel.

This project was achieved despite enormous challenges which made it an arduous process but with an outstanding final outcome.

The extraordinary pace of change in Mandurah created the first challenge. A range of studies between 2002 and 2006 revealed that there was no active reserve south of the Dawesville Channel, yet it boasted a population of 6,458 with an increase to 10,356 by 2021 (predicted). Between 2006 and May 2011 the population increased by 70%. Ocean Road Active Reserve in Dawesville was recommended for development as a priority.



Fig No. 1 City of Mandurah Showing Dawesville Channel



Fig No. 2 Area South of the Dawesville Channel

While the lack of recreational facilities in the area meant residents had to travel there was also a need to relocate sporting teams from other grounds to protect the standard of those facilities. The new Ocean Road Complex will take several sports and teams from other facilities reducing the pressure on the maintenance required.

Lack of Water Resources in Area

The scarcity of water in Dawesville was of major concern. Options that were investigated included:

- ground water;
- scheme water;
- desalination;
- synthetic turf and;
- wastewater re-use.

into the equation and it was considered that this option would not be pursued.

Synthetic Turf

While the initial idea of synthetic turf shows that the need for water to grow the turf is not required there is an ongoing use of water prior to events to keep the turf cool for players. This along with the initial costs of the turf render this option unviable for this complex especially if other alternatives are cheaper.

Following is a brief outline of the estimates for synthetic turf:

- Costs for the synthetic turf surface only - \$1,500,000
- Expected life span 6 to 8 years

Some of the arguments against synthetic turf are as follows:

- No flexibility in ground layouts
- Line marking must be pre-determined
- Players can suffer from dehydration and exhaustion due to the heat generated by the turf
- A major factor in maintenance is the possibility of dealing with fungus and bacteria within the surface.

Suggestions of using a combination of synthetic turf and natural turf as used at NIB Stadium were investigated and discarded also based on the set up costs, water required for use prior to events and the other factors above.

Waste Water Reuse

Waste water reuse has been a form of water supply in regional areas for many years so Investigations were commenced into finding a source of this water and how it could be extracted and pumped to appropriate locations for watering turf for recreational purposes.

Investigations into Reuse of Wastewater

Due to the shortage of water the City dealt extensively with the relevant bodies to source a sustainable water supply not only in Dawesville but across all of the City of Mandurah. In 2008 the City participated in an enquiry into Pricing of Recycled Water in WA to

lobby for consistency of appropriate recycled water process options and subsequent approval process as relates to government departments.

Accordingly the City received an approval for the reuse of wastewater advising that the water would be made available at no cost to the City. However, all infrastructure associated with the access to the water, underground extraction and the pumping to different locations would be borne by the City.

Desktop studies at the Caddadup Waste Water Treatment Plant (WWTP), involving hydrogeological modelling recommended the construction of a Water Advanced Treatment Plant (Tertiary Treatment Plant) and Re-Use Facility using a direct use scheme due to the potentially high salinity levels at the site.

Caddadup Waste Water Treatment Plant (WWTP)

The existing WWTP at the Caddadup site was initially analysed for the direct use scheme but there was a need for tertiary treatment of the waste water requiring the City to pay and run this treatment facility.

Costs for this approach were considered prohibitive and the ongoing maintenance and running costs of the treatment facility were beyond the City's financial capabilities.

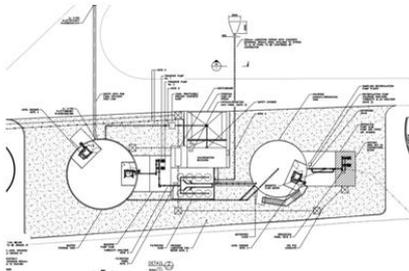
A further major risk to the City was based on the level of maintenance required for this treatment plant. If filters were not maintained regularly or there was a failure in the system there would be an immediate health risk at a major cost to the City. It would also mean that water supply could be off line for some time putting the recreation facilities at risk.

Further Hydrogeological works commenced onsite at the Caddadup WWTP and the feasibility of Managed Aquifer Re-charge (MAR) was re-assessed and found to be viable as a 10m-thick layer of low-salinity groundwater was found beneath the WWTP. This ground water layer was lying above a clay layer which would help prevent up-coning of saline water. It would cost significantly less to not only install but also cost less in ongoing operational and maintenance for the MAR scheme. The Water Corporation would supply infiltrated recycled water from the Caddadup WWTP and the City would become scheme managers.

Ironically, improvements to salinity levels over time have now made the MAR possible and a more viable alternative than constructing a

treatment plant. Major cost savings then presented the City with an opportunity to address the initial challenge.

- MAR is around 25% of the cost of the Tertiary Plant



- | | |
|----------------------------|----------------------------|
| • \$846 k cap ex | \$196 k cap ex |
| • \$22 k annual | \$7 k annual |
| • \$1.10 /kL 20 yrs | \$0.28 /kL 20 years |
| • \$0.28 /kL op ex | \$0.09 /kL op ex |

Fig No. 3 Cost Comparison of Tertiary Treatment Plant and an MAR

The project scope for the active reserve was amended with support from the Department for Regional Development, to include a larger, multi-use oval, additional car parking areas and retaining walls for seating. The increase in cost was apportioned against the reduction in costs to obtain water through the re-use bore option resulting in a project that better met the community needs.

Public and Authority Consultation

Prior to the project commencing significant consultation with the community and in particular the adjacent schools and local sporting clubs, assisted in identification of the need for active open space in Dawesville.

Consultants appointed to carry out feasibility studies conducted surveys and workshops to engage the community and stakeholders. This consultation continued during the planning phase as demands changed and the project became more of a priority. This occurred through direct contact, surveys, newsletters and via "Have Your Say Mandurah", a website set up to engage relevant community members and interested parties.

As construction neared and finally commenced, the community was kept informed through media releases, the City of Mandurah website and social media.

Due to the shortage of active space the City negotiated shared use arrangements with the Department of Education. This commenced in 2001 with an MOU and was then formalised with a License agreement which was amended, when the Ocean Road development occurred in 2015, to include water sharing costs.

During this time, the City provided feedback to the Department of Education and the Western Australia Local Government Association (WALGA) to assist the formation of a policy in relation to shared use.

Throughout the project collaboration between the Water Corporation, Department of Water, Department of Health, Department of Education and St Damien's Catholic Primary School was necessary due to the site location (adjacent to the two schools) and the waste water re-use system. The Department of Health required an extensive Water Management Plan coordinated by the City in conjunction with all stakeholders.

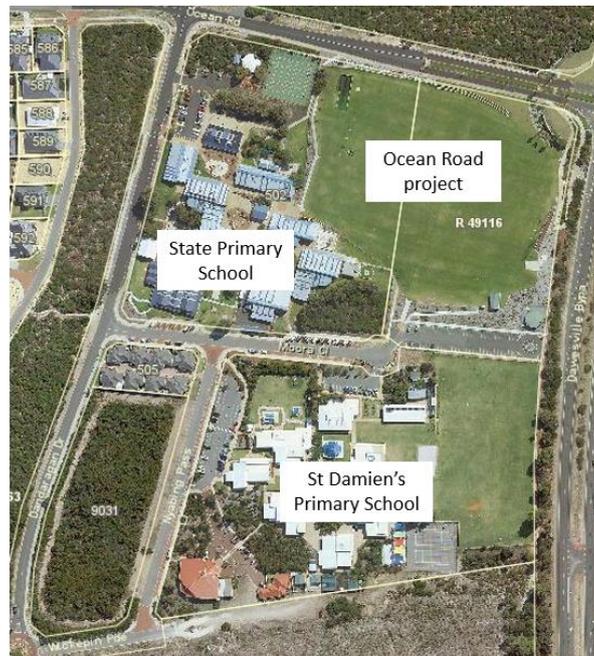


Fig No. 4 Schools Adjacent to the Ocean Road Project

Funding support required extensive collaboration with the Peel Development Commission, Department of Education and Department for Regional Development as long delays and major changes to the project scope meant communications were essential to retain the backing of these stakeholders.

This project required the active involvement of many internal City of Mandurah departments due to its complexity. In the early planning stages Recreation Services engaged consultants and worked with the community and negotiated with stakeholders. The Planning Team

provided relevant consents as did the Environmental staff who worked on obtaining clearing permits and arranging wildlife relocation.

Funding Allocations and Grants for Infrastructure

Obtaining capital was the final challenge which caused considerable delay until sourced. The initial cost of construction was estimated at \$1.2m. Funding was successfully sourced from the Department of Sport and Recreation (CSRFF), the Department of Education and the Peel Development Commission (Royalties for Regions).

A shortfall of \$700,000 became apparent in 2010 when the detailed design revealed the project was vastly under budgeted. The project came to a standstill and further funding applications were unsuccessful until 2014/15 when funding of \$1.59m was secured from the Department for Regional Development.

The following is an outline of the final funding opportunities and the final expenditure.

Budget

Royalties for Regions -	\$1,590,000
Education Department -	\$ 140,000
Peel Development Commission	\$ 284,000
Catholic Education	\$ 40,000
Total External Budget	\$2,054,000
<u>City of Mandurah</u>	<u>\$ 17,000</u>
<i>Total Budget</i>	<i>\$2,071,000</i>

Expenditure \$2,071,000

The \$2,054,000 for the construction is made up of the following items:

Description	June 2015 Value (Ex GST)	August 2015 Value (Ex GST)
Water Supply Infrastructure (including all consumer power requirements)	\$628,976	\$655,000
Site Irrigation	\$180,000	\$180,000
Site Establishment	\$50,000	\$50,000
Bulk Earthworks (including incorporation of soil amendments)	\$129,964	\$300,000
Soil Improvement	\$100,000	\$76,000
Turf	\$205,000	\$210,000
Site Infrastructure	\$350,000	\$335,000
Landscaping	\$150,000	\$70,000
Monitoring Devices	\$30,000	\$15,000
Professional Fees	\$100,000	\$100,000
Contingency	\$130,460	\$63,400
Total (Ex GST)	\$2,054,400	\$2,054,400

In focussing on the extraction and transfer of water to the site the expenditure was approximately \$655,000. The remaining funds were expended on the actual infrastructure for the formation of the ovals and the equipment to water carparking and other facilities such as practice cricket nets.

The water specific expenditure provided the following:

- Five extraction bores at the WWTP site;
- Two holding tanks 280 kL each;
- 1.3 kms of 160 mm OD High Density Polyethylene (HDPE) purple pipe;
- Two offtakes for future use at other locations in the area;
- One tank for the Ocean Road Oval 320 kL;
- Tank connection for St Damien's School 100 kL tank.

Note should be made that the feasibility for the use of the underground water (from the WWTP) required drilling bores around the WWTP, analysing the water and defining the water zone. The modelling using the bore logs etc. derived data for the input of water from the WWTP and the required distance to the extraction bores so the Department of Health was satisfied that the extracted water was of the correct quality. The distance required to cleanse the WWTP water as a tertiary process was found to be a minimum of 10 metres from entry to point to extraction point.

The costs for the monitoring bores, modelling and final data for approval was \$28,000.

So overall the costs to investigate and implement the system was \$683,000. (\$655,000 + \$28,000)

The Environmental Project Processes

From planning to implementation, all aspects of this project considered the environment. To achieve quality and cost savings the City engaged the expertise of consultants with extensive experience (some worldwide) to ensure best practice environmental outcomes:

1. Ecological Australia provides market based environmental offset services to achieve beneficial and sustainable environmental outcomes. With considerable experience in

biodiversity offsets Ecological were well placed to prepare the Revegetation Plan completed for this project which involved the clearing of native vegetation and an offset at Westbury Reserve in Dawesville.

2. Hydroplan is a specialist in securing supplies of suitable quality water, storing and treating it when necessary and then delivering it at the right flow and pressure, at the right time and place. The success of HydroPlan's proprietary in-house processes is demonstrated at Olympic venues, sports fields and golf courses throughout the world. The company were engaged to prepare the technical specification for the Water Reuse System.
3. Waste Water Reuse Scheme Investigation was conducted by Rockwater Pty Ltd who carried out extensive studies to determine the best method to achieve an oval irrigated with recycled water. Rockwater has been the go-to hydrogeological and environmental consulting firm with a proven track record of long-term clients across a range of disciplines and a core-staff possessing unrivalled experience.
4. Flora and Fauna were considered with Tuckey's Tree and Garden Service, registered with the Tree Guild of Australia, removing flora and a local Wildlife expert relocating fauna. The Tree Guild of WA is an organisation of Tree contractors dedicated to improving the professionalism of the tree industry. 1.6 hectares of flora was cleared and 949 individuals captured and relocated by Alison Dixon, an experienced wildlife re-locator. Vegetation and top soil was removed off site for future use.
5. Eco Environmental is one of Australia's largest providers of environmental monitoring equipment and supplies and distribute both nationally and internationally. Water Loggers, Atmospheric Loggers, Diver Reading Units, Water Quality Meters and Cables were supplied and installed by Eco Environmental.
6. Total Eden's core strength is found in their considerable expertise in the supply of water management solutions. Total Eden design and build a variety of water treatment solutions.

They also provide products and solutions for golf course maintenance and irrigation, sports grounds, public areas and residential sub-divisions. Their service ranges from supply through to the complete design, supply and install. Total Eden supplied design and construction of the recycled water infrastructure and installation of the irrigation system.

7. The project was managed by the City of Mandurah and drew on skills and expertise from the Infrastructure team, Finance, Recreation, and numerous officers from Works and Services Department, Environmental Services, Landscape Services and City Parks.

Technical Specification of the System

Once the feasibility established that the re-use system could provide the adequate quality of water for the area the WWTP was analysed in relation to yields and systems to get the water to the Ocean Road site.

The following information was gathered and put into the design of the system.

The annual inflow of waste water to the WWTP was initially set at 605,900 kL/annum. Annual flows will continue to increase as development increases in the Dawesville region.

The Department of Water issued a licence to the City to take water from that ground source at 120,000 kL/annum.

Based on the Ocean Road designs the initial water consumption to establish the grass and basically set up area for both schools and the community to use the requirement was initially monitored and recorded to be 43,000 kL/annum. As the development established this figure is estimated to drop to around 37,000 kL/annum.

This water quantity is to cater for the Ocean Road sporting oval (used by the public school as well as the community) which is 2.06ha and the St Damien's school oval which is 1.0 ha.

The design included five extraction bores at the appropriate location to draw water from underground with each bore pumping 1.5 l/sec despite their capacity being 5 l/sec. However this reduction was required by the Department of Water as part of the approval process.

To ensure the pumping rate in the pipeline to Ocean Road would not run dry two tanks at 280 kL capacity were constructed at the WWTP site. This

allowed the transfer of water from the WWTP to Ocean Road ovals at 7.5 l/sec without the risk of the source running dry.



Fig 5 – 2 X 280 kL Tanks at the WWTP Site

Once at the Ocean Road site the water was placed into two tanks in series. Firstly the Ocean Road oval tank was 320 kL while the St Damien's tank was 100 kL. Pumping rate between these two tanks is set at 2.5 l/sec. Once the system on one or both of these tanks dropped by 100 mm the pump at the WWTP would begin to transfer water to the tanks at Ocean Road.



Fig 6 – 1 X 320 kL Tank Under Construction at Ocean Road Oval

The pipeline connecting the WWTP and Ocean Road Site was a 160mm OD High Density Polyethylene (HDPE) purple pipe for a length of 1.3 Kms. trenched to a minimum depth of 750mm below ground level.



Fig 7 – Example of a section of the purple pipe being laid

Once the water is in the tanks at Ocean Road and St Damien's the pumps for reticulating the grassed areas operate at 8 l/sec to produce the pressure for sprinklers etc. The reticulation system is no different to any other watered parkland in the City and there were no special requirements for using recycled waste water.

Relative Cost For Scheme Water versus City of Mandurah Cost

The existing school ovals adjacent to the Ocean Road Sporting complex are approximately the same size and would use about 10,000 kL/annum. The existing Water Corporation rate for scheme water use was \$2.20/kL per annum giving a cost to both schools of \$22,000 per annum each.

The Economic Regulation Authority overseeing government charges approached the City in relation to charging St Damien's school for the water supplied by the City's system. The City is not allowed to make a profit on the water supply and were only allowed to charge the actual costs to supply water. This rate was approved at \$0.53 / kL/annum giving rise to total costs to the school of \$5,300 yielding a saving to the school of \$16,700 / annum.

Reporting Regime

Once the project was approved there were certain requirements to monitor the water quality via reports to the Health Department and the Department of Water.

Monthly testing was to be completed for E.coli as a low risk scheme less than 10 cFus/100ml and total suspended solids at the final tank – less than 30 mg/l.

An overall monthly test was to be accrued out on the bore and tanks whereby changes in:

- Salinity
- Total dissolved solids
- Total suspended solids
- pH
- temperature

Each of these tests must not change by more than 10% between reporting periods.

Each year around March/April an annual report is compiled for the following items:

- Nutrients – Phosphate
 - Nitrates
 - Ammonia
- Boron
- pH
- Electrical conductivity
- Total Dissolved solids
- Other heavy metals (too many to mention)

Again the parameters for these is no greater than a 10% change between reporting periods.

Conclusion

After undertaking fourteen years of planning, numerous studies and six years of funding applications the oval and associated water infrastructure took just seven months to construct. The City now supplies 37,000 KL of water to irrigate St Damien's Catholic School and Ocean Road Reserve.

The Reserve is used by Ocean Road Primary school and local sporting clubs including Peel Cricket and Little Athletics and has been used by Junior Football from 2016.

The construction of the oval and water system was project managed by the City of Mandurah in partnership with various local contractors including Total Eden (Irrigation suppliers), Eco Environmental, BM & RV Waters (Earth Movers), J&S Drilling and Rockwater (Hydrogeologists).

A well-researched and well-resourced project has resulted in a first rate senior sports oval with a sustainable and affordable water supply. Managed Aquifer Recharge system compared to a Treatment Plant was \$600,000 cheaper to install, \$15,000 per year cheaper to maintain.

Effective re-use of scarce water supplies in the Dawesville region has resulted in a continuous supply of irrigation water to 3.06 ha of active recreation space.

This project aimed to overcome the high-salinity ground water and narrow coastal area challenges by utilising the nearby Caddadup Waste Water Treatment Plant through a Managed Aquifer Recharge (MAR) system.

The MAR system supplies enough water to keep the new grass at a high standard without impacting on the local water supply or resulting in prohibitive costs.

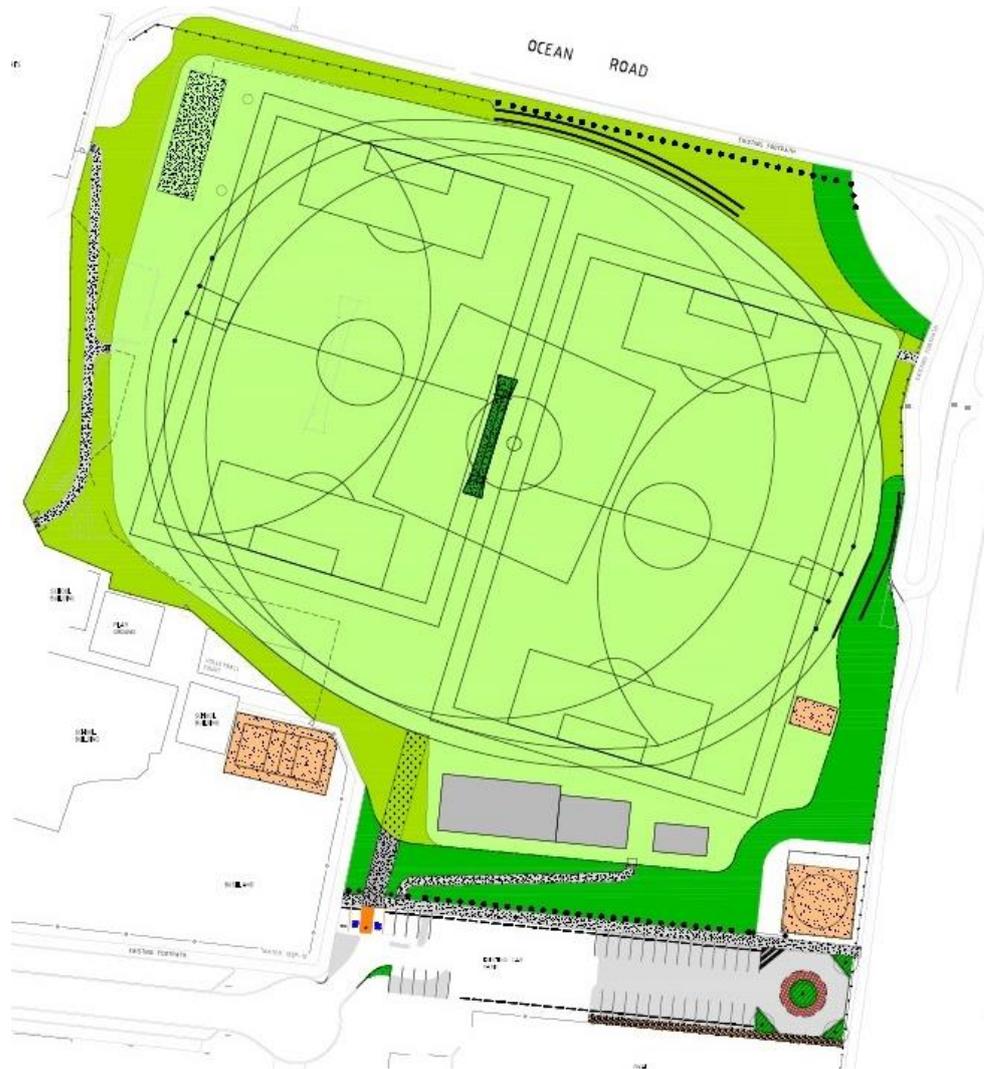


Fig 6 – Layout Plan for the Ocean Road Community Facilities

The project completed has demonstrated the viability of the MAR scheme and the quality of water using waste water and this now leads the City into a major project of extending this approach into the remaining areas using water from the Water Corporation's Gordon Road Waste Water Treatment Plant. This approach can and should be assessed throughout the Local Government sector and where financially and technically possible implemented as an alternative water supply to the conventional underground water resource.
