CRC for Water Sensitive Cities

Regional Advisory Panel Meeting
Western Region

Meeting No. 41	Meeting Minutes	9.00am - 10:00am
24/03/2020		zoom

Attendees			
John Savell	Dept. of Communities /CRCWSC EPRG	Emma Yuen	CRCWSC, Regional Manager
Loretta van Gasselt	Dept. of Planning, Lands & Heritage	Emma Monk	Dept. of Biodiversity, Conservation & Attractions
Mike Mouritz (Chair)	CRCWSC Board	Winsome MacLaurin	Dept. of Water & Environmental Regulation
Shelley Shepherd	New Water Ways Inc.	Antonietta Torre	Water Corporation
Scott Wills	Water Technology	Max Hipkins	Consultant
Barry Ball	CRCWSC		
Apologies			
Ryan Hunter	Peet	David Jones	Dept. of Communities
Greg Ryan	Development WA	Ryan Hunter	Peet
Neil Burbridge	City of Armadale	Tao Bourton	Yolk Property Group
Ajay Shah	KBR	Nick Deeks	GHD

Item No.	Agenda Topic
1.	**Welcome and apologies** The Chair welcomed all to the new teleconference format. We agreed to focus on the executive update, Business Plan, WSTN update and other business related to membership and teleconferencing.
2.	**Acceptance of previous minutes** The minutes from the last RAP meeting were accepted.
3.	**Actions from August minutes** Not addressed considering corona may change priorities.
	CRCWSC Updates
4.	**Executive update** CORONA AND THE CRCWSC: Barry went over how the research adoption program will adapt to the current situation.

Item No.	Agenda Topic
	They are looking into online delivery of the tools and products for the next 3 months They have considered different levels of engagement and different future scenarios. Everything is in flux but want to focus on engaging as best we can in order to meet the hard deadline for July 2021. This uncertainty extends to how next year's budget will be allocated. <u>WSCI:</u> EPRG met at end of February and discussed the Institute. There was interest from UQ and Monash for ownership and only limited discussions with UWA who possibly want to be more of a partner than an owner. However, the current shock to universities with loss of international student income will probably mean it is a long time before people can invest in anything. Watercorp were waiting for more details around ownership and will not be in a position to make a decision for a while <u>ONGOING TOOL ACCESS:</u> Tools and products need to maintain some access post June 2021. If it isn't the WSCI providing this service then there needs to be a scaled down version to keep the wheels turning over. ACTION: BB will give an update on Adoption activities post Covid-19 at the next meeting
4.	**WRAP discussion around Corona and implications for state government** State budgets will be put on hold a few months but this doesn't change the CRCWSC deadline of June 2021. Some agencies are bringing forward more relevant work for this time. Some agencies are only doing the essential work and putting everyone on holidays State agencies are told to carry on and continue as best they can All will have trouble getting input from others with so many on leave Government needs to deliver core functions and people may be reallocated to other areas of work. From a planning perspective, water ranked at the lowest priority while bushfire is obviously higher. There is a strong role for the think tank to provide thought leadership on how to respond to these types of crises - valuing liveability, similar problems of how to respond to climate (ie ultimately water) and to lay the foundations of the future. We have an opportunity to plan and position around any projects still going ahead. There may be some in development WA. ACTION: EY to ask state developers about any projects that are going ahead.
5.	**Regional Manager Report** Business plan was approved subject to comments by Emma Monk and Shelley Shepherd being incorporated. It is acknowledged that it is out of date but that we would adapt in the rapidly changing environment. ACTION: EY to amend the business plan and issue as a final

Item No.	Agenda Topic
	Items for discussion
6.	**Capacity Building** NWW has cancelled all face to face events and what can be done is being done via webinars. Shelley asked the WRAP whether to send out the newsletters and there were two opinions 1) repurpose what we do in the context of COVID to fit in the changing landscape 2) provide a distraction from Covid and show the world goes on and the positive stuff around how people are making WSC work. It was agreed the newsletters would be sent and to provide positive messages. ACTION: SS to continue sending NWW newsletters so there are good news stories to distract from the Covid-19 crisis.
7.	**TAPS2 / Scenario tool** Christian is searching for topics for the webinars. ACTION: ALL to notify AT of topics for TAP2 webinars. ALL, particularly WM to provide AT with suitable text for the guidance notes so that they are relevant internationally. **TAPS1/ A/ Management database** There is an opportunity to provide feedback on the index tool TAPS. DWER were concerned that groundwater is not well covered in the index and whilst the indicators don't need to change, the guidance notes should be tweaked to reflect better how existing indicators are about groundwater too.
8.	**IRP1** This was not discussed.
9.	**IRP2** This was not discussed.
10.	**IRP3** This was not discussed.
11.	**IRP4** This was not discussed.
12.	**IRP5** This was not discussed.

CRC for Water Sensitive Cities

Item No.	Agenda Topic
13.	**WS Transition Network** Action 30 (p19) of the Waterwise Perth Action Plan is to 'Explore collaboration with industry, local governments and the CRC for Water Sensitive Cities to extend science and modelling to support water planning and policy'. At the most recent Waterwise Steering Committee meeting (26 February 2020), it directed the Waterwise Working Group to 'Work with the Water Sensitive Transition Network and the Office of Science to provide advice and recommendations on prioritised science, research and adoption needs for State government to accelerate waterwise outcomes, including options for delivery and options for investment models.' It is important to ensure that the recommendations on prioritised science, research and adoption needs for waterwise have taken into account the State government and Office of Science priorities. It will be embedded in the water wise Perth action plan: Next steps are to engage a consultant who will 1) review existing work to come up with research science needs (including liveability workshop, gaps from IRPs, etc) 2) share with Waterwise Working Group, Waterwise Steering Committee, Office of Science and begin shortlisting the criteria. 3) work with WSTN stakeholders for their feedback 4) WSTN and DWER and Steering Committee will then need to work out what is the content. 5) Then the groups will agree recommendations on options for delivery and options for investment models
14.	**Events** This was not discussed.
	Other business
15.	**Other Business** Quorum We only just formed a quorum at this meeting and discussed the difficulties this poses going forward. It was agreed to: 1) Remove long absent WRAP members who haven't attended in the past 12 months and are not participants of the CRCWSC. In particular, Neil Burbridge and Ajay Shah. 2) Create a list of formal WRAP members for decision making (hence required for quorum), and an additional list of WRAP stakeholders who will still be circulated all papers but not formally considered a member. 3) WRAP stakeholder are permitted to attend WRAP at the invitation of the Chair or Executive Officer. 4) The Chair will gauge interest from members who haven't attended more than three meetings 5) Send out an EOI for LGA members to fill any gaps Feedback on undertaking Zoom meetings:

Item No.	Agenda Topic
	There were a few issues with access to working technology but members are adapting and we should continue to use it during times of social distancing. ACTION: EY to send out email inviting those on the current WRAP circulation list to clarify their interest in ongoing WRAP membership EY to send out an EOI for a LGA member to fill any gaps.
16.	**Close:** The meeting closed at 10.00am. **Next meeting:** Zoom on Tuesday 26 May

CRC for
Water Sensitive Cities

WESTERN Regional Advisory Panel

ACTIONS

Legend
Done
Not Done
Deferred
On Agenda

Actions	Description	Who	When
	Actions from Meeting No. 41		
	Give an update on Adoption activities post Covid-19 at the next meeting	BB	
	Ask state developers about any projects that are going ahead.	EY	
	amend the business plan and issue as a final	EY	
	Continue sending NWW newsletters so there are good news stories to distract from the Covid-19 crisis.	SS	
	ALL to notify AT of topics for TAP2 webinars.	ALL	
	ALL, particularly WM to provide AT with suitable text for the guidance notes so that they are relevant internationally.	ALL	
	Send out email inviting those on the current WRAP circulation list to clarify their interest in ongoing WRAP membership.	EY	
	Send out an EOI for a LGA member to fill any gaps on WRAP.	EY	
	Outstanding actions from previous meetings		
	CRCWSC to put together scope, list of priority topics, cost and approach for developing landing pages and then seek national CRC funding for landing pages.	EY	

Actions	Description	Who	When
	Emma Yuen to follow up with Natasha from DWER and Tanith from Mandurah. Antonietta Torre will check up with DWER drainage for liveability for interest in using INFEWS	EY	
	GR/ Steve Kenway to provide additional cost to include heat in Knutsford case study	GR	
	future WRAP to discuss the mainstreaming workshop outputs.	EY	

Western Region Manager Update

WRAP 26 May 2020

Activity title	Outcomes achieved	Items for RAP to note
CRCWSC executive	The executive is exploring changes to adapt to a post covid-19 environment.	
CRCWSC Board	All future board meetings will be undertaken virtually. The Audit and Risks committee will meet in May and CRCWSC Board will approve budgets 10 June.	
CRCWSC AC		
CRCWSC commercial	International commercial work has been significantly impacted by Covid – 19 Delivery of domestic commercial work has also been impacted by travel restrictions	
EPRG	Met May with a focus on the implications of covid-19	
Research including Tranche 1 and Tranche 3	Research teams are scaling back to focus on commonwealth agreed deliverables. CRC for Water Security is a new CRC that is preparing a bid with the Water Sensitive Institute as a partner. RESTORE tool evaluation provides a review of the application of the beta tool applied in Queensland. An updated version of the tool will be released in May.	For information: Differentiation between Institute and CRC Water Security will be provided in meeting. For information: RESTORE tool evaluation for scrubby creek.
General operations and Regional Manager	The business plan has been finalized (for the pre-covid context) and was circulated to members.	For information: Final Business Plan attached For discussion: need to consider exit strategy for WRAP
Transition Network	WSTN will be holding an onsite session at Wharf street 12 May and a zoom meeting on 19 May. Many subcommittees continue to hold virtual meetings.	
Adoption - WA Research and Adoption Plan	The tools and products Roadshow has been cancelled and the adoption program will be adapted to the post-covid environment.	
Adoption - IRP1 Shelley	Report on principles for engaging communities in WSC transitions has been released. Project team still to develop Guidance manual for enhanced envisioning process methodology (A4.2 deliverable) and the Technical report on comparative analysis of case study results.	For information: How to Engage communities in wsc transitions report
IRP2 Emma	Ideas for Financing was held late April. It was restricted to regulators but was facilitated by Synergies (WA based economic consultant)	For information: Any Participant nearly ready with an INFFEWS application can receive support from Liz soon.
IRP3 Shelley	Brabham case study and the Governance reports were released as documented in this news item. The Brabham case study includes ingredients for successful multi stakeholder collaboration is discussed in this news item. A summary of the recommendations from these report and the IRP5 report is attached. Draft report on collaborative governance considered by PCG. Project team is still working on the framework but it is unlikely that it will link to any of the TAPs program.	For information: IRP3 Perth development planning and governance Report IRP3 Brabham Collaborative process report
IRP4 Greg	The open panel session planned for 31 March was cancelled. The typologies catalogue and the evaluation framework were circulated for comment and no comments were received from WA at time of writing. The IRP4 Team, DoC, Design WA and Development WA are trying to coordinate a virtual design charette via a combination of zoom and face-face meetings. The request for a quote for urban heat at Knutsford has been sent to the commercial team. Antonietta investigated a peer review of the Urban water mass balance model and its applicability to Perth	For information: Case studies for the design charette will be discussed in-session
IRP5 Ant	The Expert Panel guidance document shared last meeting has been finalized and being published. Next step is commencing Work Package 2 – selecting the field validation sites, design the field validation program and developing the Sampling & Analysis Plan. However, funding is available to undertake the field validation for water balance (quantity) only, and not water quality or evapotranspiration of vegetation (a key component of the water balance that was identified as a knowledge gap by the Expert Panel).	For discussion – how to fund water balance (water quality or evapotranspiration of vegetation?
TAP1 - WSC index ant	The following are on hold until July 2020: 1. Management Actions Module. 2. The Transition Dynamics Framework (TDF) module. 3. online tool that relates the WSC Index to the UN Sustainable Development Goals (SDGs). Antonietta is progressing guidance for the index RCWSC has proposed a methodology for online Index workshops which is likely to be trialed with the City of Stirling	For discussion: Antonietta is seeking feedback on the Index tool.
TAP2 – scenario tool at planning scale Ant	Previously planned training is on hold and being reviewed post-covid. TARGET was launched 29 April and a video will be available on youtube soon. Monthly training webinars are available. The scenario tool provides a quick start guide and introduction found within the scenario tool . Ant is seeking feedback on future seminar topics	For discussion: Antonietta is seeking topics for Monthly training webinars. Face sheet on scenario tools: Factsheet for Scenario Tool
KAT – capacity building and community engagement Shelley	Face to face engagement has been significantly impacted by Covid • Waterwise Masterclasses put on hold until June (hopefully) (delivered planning for resilient cities) • Fact sheets on water sensitive transport, tourism and health are attached for comment until Friday 12 June. • Introductory WSUD training sessions changed to 3 x 2 hour online sessions held during May. The Groundwater session was held on 5 May (38 participants), LWMS on Tuesday 12 (38 participants) & Tuesday 19 May will be retrofitting and maintenance. The webinar has been an effective way of delivering these sessions and is likely to continue. • Hydropolis rescheduled to 20 & 21 October at DWER • WSUD module for LG Councillors in being drafted • New videos of Carolyn and Carlos are on NWW website	

Activity title	Outcomes achieved	Items for RAP to note
	• Other NWW activities have been rescheduled due to COVID19 restrictions. Now focusing on improvements to the website (all suggestions welcome), preparation of a fact sheet and case study on green walls, short videos of LG people who like WSUD (2) and preparation of an INFFEWS case study (suggestions welcome). The AWA Mentoring program has started and is open for both mentors and mentees until May 31. EOI for preparation of CRCWSC website case studies was circulated in May but no WA SME applied.	
WSTN Winsome	Action 30 (p19) of the Waterwise Perth Action Plan is to 'Explore collaboration with industry, local governments and the CRC for Water Sensitive Cities to extend science and modelling to support water planning and policy'. At the most recent Waterwise Steering Committee meeting (26 February 2020), it directed the Waterwise Working Group to 'Work with the Water Sensitive Transition Network and the Office of Science to provide advice and recommendations on prioritised science, research and adoption needs for State government to accelerate waterwise outcomes, including options for delivery and options for investment models.' Rob Karlese has been engaged to undertake this work.	
Opportunities – policy		
Opportunities - Projects		
Grants and Funding		
Analysis: Evaluation		
events	Water events calendar has moved to the MS teams site. 20-21 October Hydropolis 2020 Conference: water sensitive stormwater is BAU. Information available here	
Media	Our first Couch Time conversation is available here and relates to our recently release Guidelines. Guidelines for Passively Irrigated Landscapes. The Texans research is to be showcased in Irrigation Australia based on a previous watersense article. IRP4 session at NSW DPIE open to non-department staff accessed via the DPIE Education Channel Aboriginal elders and custodians from the Western Arrernte people, Central Arrernte people and Warlpiri people in Central Australia. 'Kwatja Ngkama' is the Western Arrernte translation for 'Talking Water'. Productivity commission released research paper on "Integrated Urban Water Management — Why a good idea seems hard to implement"	Designing for passively irrigated guideline Article on Texan researchers looking at Perths Water Security Productivity Commission and integrated water management Report
Stakeholder engagement by Regional Manager	CRCWSC released "Principles for engaging communities in water sensitive city transitions" for policymakers and practitioners, especially local and state government, water utilities and catchment management authorities. CRCWSC are producing a guide on virtual collaboration https://watersensitivecities.org.au/content/coming-soon-tips-for-better-online-engagement/ I have met with: • NESP2 'Sustainable Communities and Waste' hub with Jane Heyworth and Byran Boruff • Subi East community reference group (as a local resident not in a professional capacity)	Principles for engaging communities in water sensitive city transitions.
Development sector engagement	UDIA water committee continues to meet and there was a session from Nick Turner on the North East Corridor water supply. Potential to present on the Brabham reports at a later stage.	
Local Government sector engagement	AWA mentoring event originally planned to target LGAs. WALGA session with Urban Forest Working Group on Trees in a Liveable City: An Urban Forest Conference was put on hold	
Water utility engagement	Water wise councils Platinum is going online Thursday 21st and 28th May at 9:30 book here https://docs.google.com/forms/d/16p_PGr-i2JgLRtsFh8TUVNhxVEho3zYRZRxLuRLGDLw/viewform?edit_requested=true	

CRC for
Water Sensitive Cities

Current Formal WRAP members with decision making rights	
Mike Mouritz (Chair)	Former CRCWSC Board
Emma Yuen	CRCWSC, Regional Manager
John Savell (proxy David Jones)	Dept. of Communities /CRCWSC EPRG
Loretta van Gasselt (or proxy)	Dept. of Planning, Lands & Heritage
Shelley Shepherd	New Water Ways Inc.
Scott Wills	Water Technology
Emma Monk	Dept. of Biodiversity, Conservation & Attractions
Winsome MacLaurin	Dept. of Water & Environmental Regulation
Antonietta Torre	Water Corporation
Max Hipkins	Consultant
Ryan Hunter	Peet
Greg Ryan	Development WA
Nicholas Deeks	GHD

Regular WRAP observers	
Barry Ball	CRCWSC
Lorena Taylor	CRCWSC

WRAP distribution list	
Anas Ghadouani	UWA
David Jones	Department of Communities (proxy for John Savell)
Damien Pericles	REALM
Liz Petersen	Advanced Choice Economics
Tao Bourton	Yolk Property Group
Tba	City of Canning
Tba	City of Mandurah
Tba	City of Melville
Neil Burbridge	City of Armadale

Proposed meeting times

4th week of every second months	Date	Available times
Monday 9-3	27 July, 21 September, 23 November	
Tuesday 1-3	28 July, 22 September, 24 November	
Wednesday 1-3	29 July, 23 September, 25 November	
Thursday 9-3	30 July, 24 September, 26 November	

CRC for
Water Sensitive Cities

Watery events

Title	Location	Start Time
WSTN meeting	webinar	19/05/2020 9:30 AM
NWW training - retrofitting and maintenance	webinar	19/05/2020 1:30 PM
Waterwise Platinum Council webinar session 1		21/05/2020 9:30 AM
WRAP meeting		26/05/2020 9:00 AM
Waterwise Platinum Council webinar session 2	webinar	28/05/2020 9:30 AM
Sustainability, Research and Innovation Conference	Brisbane	14/06/2020 12:00 AM
National Stormwater Conference	Crown Promenade Melbourne	17/06/2020 12:00 AM
WSTN Tech Capacity & Partnerships Subcommittee	DBCA, Kensington	25/06/2020 10:00 AM
WSTN Tech Capacity & Partnerships Subcommittee	DBCA, Kensington	3/09/2020 10:00 AM
15th IWA/IAHR International Conference on Urban Drainage	Melbourne Convention Centre	6/09/2020 12:00 AM
AILA "spectacle and collapse"	Perth WA	20/10/2020 12:00 AM
WSTN Tech Capacity & Partnerships Subcommittee	DBCA, Kensington	12/11/2020 10:00 AM

Business Plan 2019/2020

Western Regional Advisory Panel
December 2018

CRC for
Water Sensitive Cities

CRCWSC and the WA context

In Western Australia, there are a wide range of stakeholders seeking to drive a Water Sensitive Agenda. The most significant achievement by state government has been the release of the Water Wise Perth Strategy in October 2019. While the Departments (DWER, DBCA and DPLH) and UWA have long been supporters of water science and policy, the engagement of a broader group of stakeholders through the CRCWSC has provided additional opportunities. The Water Corporation board has set ambitious targets, the state developers (Department of Communities and Development WA) are undertaking innovative developments in Brabham, Bentley, White Gum Valley and Knutsford. Meanwhile, local governments are increasingly undertaking Index and Transition Strategy workshops which lead on to actions incorporated into strategic plans and local sustainability strategies.

The local development sector has been subdued since 2014 which tends to dampen any appetite for risk through innovation. Ironically, timelines are not as critical during property slumps and innovation is best achieved at these times. Perth currently has low rates of infill, and compared to other capital cities, has the highest proportion of residential completions from greenfield estates compared with apartments. Many of these new Greenfield developments are in areas without a groundwater licence for public open space irrigation and or experience high groundwater levels in the winter months. The ‘easy’ development sites close to the city have invariably been developed and Perth is left with these more challenging sites. However, these emerging problems for development have the potential to also open doors where water sensitive approaches are shown to be an answer to an existing problem.

The impacts of climate change have been evident for several decades in southwest WA which has seen the water sector take swift and decisive action through climate independent supplies such as desalinisation. Meanwhile momentum is gathering around protection of the urban tree canopy at the state level through DPLH and the WALGA Urban Tree Canopy working group. At the same time the health sector is poised to tackle the impacts on health in the wake of the Sustainable Health Review, and the Climate Health WA inquiry. The convergence of healthy communities under climate change and greening our suburbs has the potential to embed water sensitive practices across Perth.

About the Western Regional Advisory Panel

Regional Advisory Panels (RAPs) are a key component of the CRC for Water Sensitive Cities' (CRCWSC) management structure. These Panels enable state-level coordination of end-user priorities and involvement in CRCWSC research activities, as well as tailoring of capacity building activities.

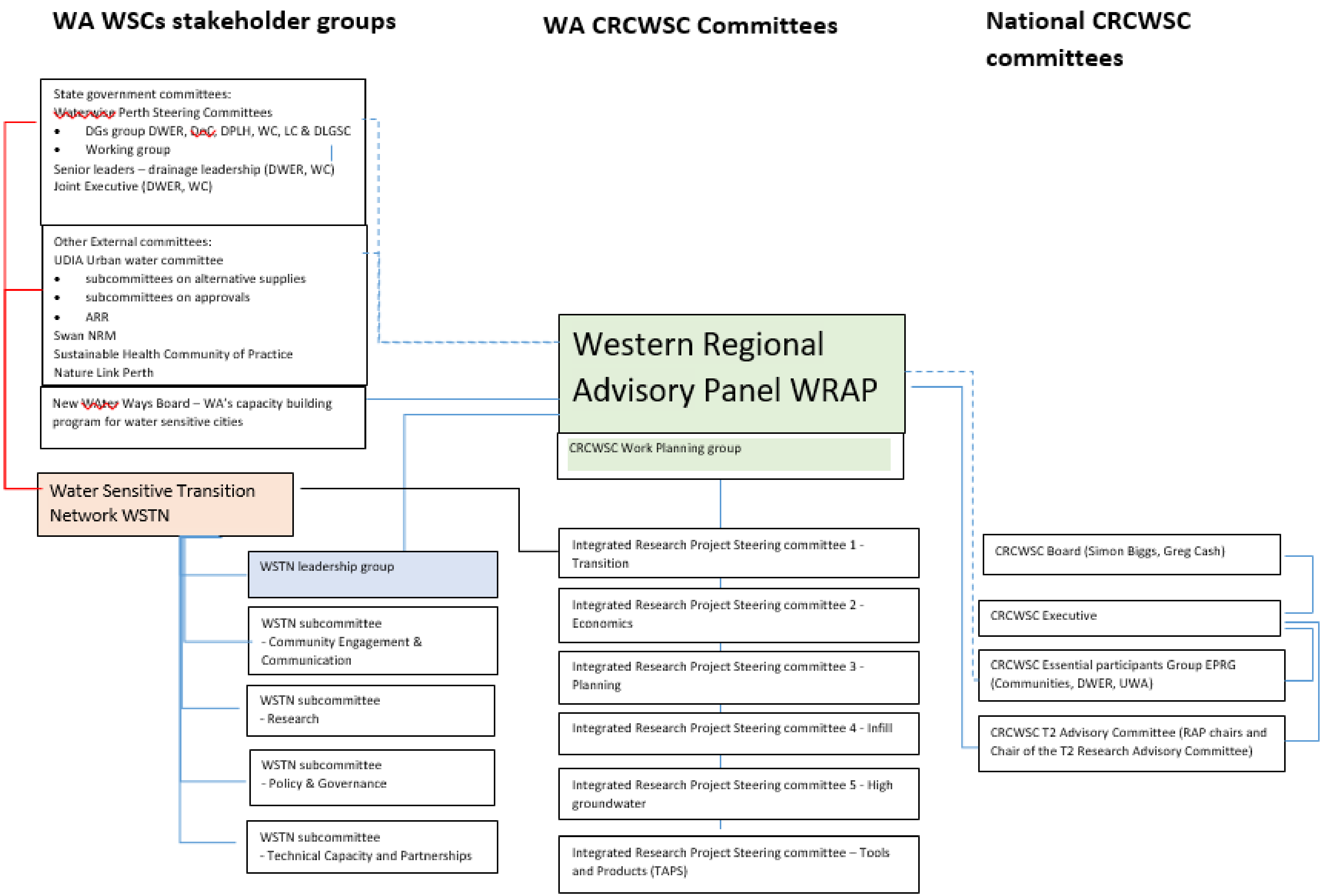
The Western Regional Advisory Panel (WRAP) is composed of officers from government, councils, water utilities, developers, consulting organisations and capacity building organisations who are invested in transforming Perth into a water sensitive city. In early 2019, WRAP membership was opened to all participants, including individual Local governments and SMEs, and key gaps in the development and planning sectors have been filled by non-participant stakeholders.

Current members of the WRAP can be found at https://watersensitivecities.org.au/creating-wsc-australian-cities/wsc-wa/regional-advisory-panel-wa/

The purpose and role of the Regional Advisory Panel is outlined in its Terms of Reference which states it will act as an advocate and steering committee for CRCWSC programs to advance the transition to water sensitive cities and towns in their region. The WRAP is focussed on providing strategic guidance to the CRCWSC Regional Managers, Executive and Board to ensure that the CRCWSC program activities (e.g. Integrated Research Programs, Tools products and Capacity Building) address the priorities of regional CRCWSC Participants and stakeholders.

The WRAP is connected to a network of other groups, both within and outside of the CRCWSC who are pursuing a water sensitive Perth. Of note is the Water Sensitive Transition Network (WSTN) who has prioritised actions via their transition strategy and implementation plan to help Perth transition to a water sensitive city whilst supporting key stakeholders in their organisational goals.

These groups are illustrated on the diagram below:


WA WSCs stakeholder groups
WA CRCWSC Committees
National CRCWSC committees
State government committees:
Waterwise Perth Steering Committees
DGs group DWER, DoC, DPLH, WC, LC & DLGSC
Working group
Senior leaders – drainage leadership (DWER, WC)
Joint Executive (DWER, WC)
Other External committees:
UDIA Urban water committee
subcommittees on alternative supplies
subcommittees on approvals
ARR
Swan NRM
Sustainable Health Community of Practice
Nature Link Perth
New WAter Ways Board – WA's capacity building program for water sensitive cities
Water Sensitive Transition Network WSTN
WSTN leadership group
WSTN subcommittee - Community Engagement & Communication
WSTN subcommittee - Research
WSTN subcommittee - Policy & Governance
WSTN subcommittee - Technical Capacity and Partnerships
Western Regional Advisory Panel WRAP
CRCWSC Work Planning group
Integrated Research Project Steering committee 1 - Transition
Integrated Research Project Steering committee 2 - Economics
Integrated Research Project Steering committee 3 - Planning
Integrated Research Project Steering committee 4 - Infill
Integrated Research Project Steering committee 5 - High groundwater
Integrated Research Project Steering committee – Tools and Products (TAPS)
CRCWSC Board (Simon Biggs, Greg Cash)
CRCWSC Executive
CRCWSC Essential participants Group EPRG (Communities, DWER, UWA)
CRCWSC T2 Advisory Committee (RAP chairs and Chair of the T2 Research Advisory Committee)

Goal of this business plan

In 2019/20, the emphasis is on delivery of the five Integrated research programs (IRPs) and various Tools and Products (TAPs) including the Scenario planning tool, the city shaping platform, WSC Index, Transition Dynamics Framework (TDF), Synthesis workshops INFEWS economic tools, Infill framework and typologies catalogue. This business plan is for the WRAP only and doesn't cover the Water Sensitive Transition Network. Key objectives for the WRAP include:

- improve translation and access to knowledge generated to date;
- improve pathways for the CRCWSC research to influence 'on-ground' projects;
- demonstrate end-user value from the investment in research;
- facilitate adoption of CRCWSC research and tools through the NWW program

Relationship to other plans

The Plan articulates what the partnership between the CRCWSC and its end-user organisations aspires to deliver in WA, provided adequate resources are identified. It achieves this by providing a set of outcomes (success measures) and outlining high-level actions that will deliver them. This plan will guide the efforts of the WRAP, which in turn provides advice to the CRCWSC on research and adoption.

The plan will be guided by National plans:

- CRCWSC Strategic and Operations Plans (released October 2019).
- Research and Adoption Portfolio Action Plan (2017-2021) - a national scale plan including actions and performance targets.
- Key commonwealth milestones for the CRCWSC

The plan will be aligned with and support local plans:

- The WSTN's Perth Transition Strategy (Part A and B) and subcommittee priorities.
- New WAterWay's local work programs (CRCWSC knowledge broker and capacity building activities in WA).
- The WA state government's Water Wise Perth Action Plan.

Resources available to deliver the business plan

The proposed activities of the CRCWSC in WA will be delivered through a mix of:

- CRCWSC Tranche 2 activities and services which include integrated research projects, tools and products, regional projects and the WA Transition Strategy and Implementation Plan;
- A CRCWSC budget for capacity building activities in the Western region;
- Commercial products including fee-for-service CRCWSC activities (e.g. “Ideas for” workshops, application of the Transition Dynamics Framework, WSC Index benchmarking workshops, etc.);
- CRCWSC staff including the WA Regional Manager;
- In-kind contributions and participation or partnerships with end-user organisations.

Integrated Research Projects and Regional Projects

The CRCWSC is delivering its 2016 - 2021 research program through 5 Integrated Research Projects (IRP1- IRP5) and a Tools and Products (TAPs) project. Each project has a Project Steering Committee comprised of CRCWSC member organisations. The Projects include a mix of case study projects nominated by the Regional Advisory Panels. WA case studies within the IRPs include:

- Perth Transition Strategy
- Belle View Estate wetlands
- Subiaco strategic resource precinct
- Knutsford Museum site

- Brabham development
- Ocean Reef Marina and other ideas for projects.
- Various LGAs undertaking benchmarking or transition planning

In WA we also have at least 5 Regional Research Projects:

- REG 6-1 Eric Singleton Wetland Data Analysis
- REG6-2 Protection of urban waterways: Eric Singleton Wetland and Heron Park sediment discharge
- REG6-3 Green walls in Mediterranean climates: improved liveability and lower water and energy use
- REG6-4 Hydrological monitoring, water balance and hydrological performance Anvil way living stream and Wharf street wetlands
- REG6-6 Hydrological nutrient modelling of Swan Canning.

Finally, there are several potential WA case studies related to the tools and products including:

- Hartfield park,
- Hamilton Hill,
- Etc.

Capacity Building, Knowledge Brokering and Adoption Budget

Under the Knowledge and Translation (KATs) program there is financial support for participant states to undertake capacity building with their local stakeholders. The WRAP has engaged New WAter Ways (NWW) to deliver capacity building and research adoption activities and products. NWW was formed in 2006 and incorporated in 2014 with the aim to build the water sensitive urban design capacity of government and industry. Activities are guided by the NWW Board agencies, who also contribute funding and in-kind resources. In the 2019/2020 Financial Year, the CRCWSC through the WRAP will provide $40,000 to NWW to undertake additional capacity building on its behalf. There is no guarantee that the same amount will be available in 2020/21. The activities delivered by NWW on behalf of the CRCWSC are consistent with the *CRCWSC knowledge broker and capacity building activities in WA – update May 2019* and endorsed by the WRAP.

There is also funding at the national level for capacity building activities that are nationally relevant activities.

Targeted services such as the WSC Index and Research Synthesis projects

The CRCWSC offers a range of services to support the implementation of integrated water management. These services are offered to benefit individual organisations (whether CRCWSC members or external organisations) to draw upon the research and adoption activities developed within the CRCWSC. Examples of projects delivered to date include:

- **Benchmarking -** the water sensitivity of cities and municipalities using the WSC Index Tool;
- **Visioning and transition strategy** – creating stakeholder alignment and an implementation strategy around the agreed vision from the 'Shaping Perth as a water sensitive city' report (project A4.2), as well as facilitating local governments including City of Perth, and/or regional cities/towns through a transition planning process (IRP1);
- **Research Synthesis** projects – co-design, with researchers, water sensitive city designs and solutions for specific locations;
- **Investment Framework for Economics of Water-Sensitive Cities (INFEWS)** – non market valuation tool and the Cost Benefit Analysis tool
- **Demonstration projects** – e.g. Detailed case studies and short case studies published on the CRCWSC's website
- **Consulting projects** – for instance facilitating workshops, where CRCWSC may be the lead consultant or a sub-consultant.

The Regional Manager

The Regional Manager has been funded part-time (0.7 FTE ~ 15 days a month) until the end of the 2021 by the CRCWSC. The key activities of the WA Regional Manager include:

	Key activities	Percentage of time
1	Provide support to WRAP Chair and WRAP;	10%
2	Support the implementation of CRCWSC programs including IRP1, IRP2, IRP3, IRP4, IRP5, TAP platform, KAT, Ideas/Synthesis, CRC forums	50%
3	Support the IRP5 PSC and EP	10%
4	Influence through supporting NWW, WSTN, UDIA forums, and direct engagement with key sectors: development, Local Government, and Water Utilities	20%
5	Inform through presentations and engagement with stakeholders	10%

CRCWSC stakeholder engagement activities

Occasionally the CRCWSC undertakes targeted stakeholder engagement activities to advance the adoption of water sensitive cities. These are supported by CRCWSC staff including the Regional Manager, Adoption Manager, Chief Research Officer and CEO as well as support staff. Examples include:

- workshops with key stakeholder groups communicating the CRCWSC research, products, tools or services;
- preparing submissions on key issues on behalf of participants and key stakeholder organisations;
- leading round table discussions or workshops; and
- convening working groups on strategic issues.

Transition Network

The Water Sensitive Transition Network (WSTN) is a group of CRCWSC participants and non-CRCWSC participants who support the transition to a water sensitive city in greater Perth. Membership of this group is open to all CRCWSC participants in WA, as well as other engaged stakeholders not formally part of the CRCWSC.

The Western Region has developed a Transition Strategy through Integrated Research Project 1 with support of the Transition Network. The Transition Implementation plan has been finalised mid-2019 and outlines key actions the WSTN will move forward via the subcommittees related to Policy and Governance; Community Engagement and Communications; Technical Capacity and Partnerships; and Research.

Contributions by participants and partners

CRCWSC participants support the objectives of this business plan by attending WRAP, Essential Participants Reference Group (EPRG), CRCWSC Board and IRP Project Steering Committees, in addition to providing venues and other in-kind contributions.

In addition, they continue to support and facilitate actions that support a water sensitive city at an organisation or sector level including:

- Department of Water and Environmental Regulation: Leading development and implementation of the Waterwise Perth Action Plan, supporting Waterwise Council Program (a joint initiative with Water Corporation) and supporting New WAter Ways

- Department of Communities (Housing): Undertaking water sensitive developments including Bentley Greenwalls and Brabham urban development; supporting implementation of the Waterwise Perth Action Plan

- Development WA: Undertaking exemplar developments incorporating water sensitive principles, including Knutsford and Hamilton Hill and Ocean Reef urban developments; supporting implementation of the Waterwise Perth Action Plan

- Water Corporation: Created a Waterwise Cities team in 2018 to lead a coordinated waterwise cities program; implementing their Board's strategic objectives which align with the goals of a WSC; supporting the Waterwise Council Program (a joint initiative with the DWER) including subsidising the WSC Index benchmarking workshops for councils; supporting New WAter Ways and supporting implementation of the Waterwise Perth Action Plan

- Department of Biodiversity, Conservation and Attractions: Funding research around water in and around the Swan Canning catchment through Regional Projects and supporting New WAter Ways.

The WRAP also partners with non-CRCWSC participants both directly and via the NWW board who actively support WSC principles, including:

- Department of Planning, Lands and Heritage: Incorporating of WSC principles into State Planning Policy 2.9 Water Resources, Design WA, etc, participation in CRCWSC processes; supporting implementation of the Waterwise Perth Action Plan and supporting and supporting New WAter Ways

- Urban Development Institute of Australia (UDIA): Supporting engagement via the UDIA Urban Water Committee, which has identified “Alternative water supplies” and “Smoothing Approvals” as key issues.

- Western Australian Local Government Association (WALGA) and non-participant local governments: Providing access to their network of local governments to facilitate knowledge sharing and supporting New WAter Ways.

In addition to in-kind and projects, many also provide cash contributions directly into the CRCWSC activities through Regional Projects (REG) into the high groundwater project (IRP5) and into actions related to the Water Sensitive Transition Strategy (e.g. Noongar knowledge).

Cash contributions from the CRCWSC

The table below provides the cash contributions made to the Western Region by the CRCWSC excluding research and centralised activities such as commercial, communications and operations.

Activity for	**CRCWSC funding for WA in 2019/2020**	**CRCWSC funding for WA in 2020/2021**
WRAP operations	$10k	TBC
Regional Manager	$90k	$90k confirmed to June 2021
Capacity Building • New Waterways • National activities	 $40k (WA only) Tbc	TBC

What does success look like in 2021?

IRP5: Socialise Expert Panel recommendations and share research findings with stakeholders engaged in policy review and formulation including:

- Water management policies for high groundwater areas undergoing urban development.
- BUWM water monitoring guideline.
- IPWEA (subdivision) guidelines.

IRP4: Apply the 'Infill Performance Evaluation Framework' and 'Infill Typology Catalogue' across the Industry in Perth

- Workshop with Design WA in early 2020 with IRP4 team
- Meeting and presentations with WRAP, WSTN, Dev WA, Communities, METRONET and other key stakeholders in March with IRP4 team.
- Establish an engagement process to encourage Development WA/ Communities to use the catalogue/ evaluation framework in future developments and link to waterwise Perth responsibilities

IRP4/TAPS: Apply the Water Mass Balance in Perth

- The IRP4 Water mass balance tool (i.e. small scale and detailed) is applied to a WA case study and Infill evaluation assessment framework. Then validated by researchers or experts hence making it accessible for use by other practitioners.
- CRCWSC partners trial the Scenario planning tool water mass balance module in TAPS2 (i.e. larger scale, less detailed) which assesses the interactions between centralised and decentralised supply options and potentially groundwater supplies.
- Shares information to support the inclusion of the water mass balance tool in other modelling applications such as that by sentient hubs.

IRP3: Embed the learnings from the Brabham case study report in the planning system

- Share outcomes with project stakeholders (Department of Communities and Peet) and other stakeholders including Development WA and participants on WSTN. This will create a greater understanding of efficient approval processes and barriers to innovation in a way that facilitates buy-in for shared solutions.
- Targeted meetings with WAPC, DPLH, UDIA urban water committee and DWER potentially attended by Chris Chesterfield.

IRP2: facilitate awareness and use of the Investment Framework for Economics in CRCWSC participant processes:

- A meeting is coordinated with WA treasury, ERA, Infrastructure WA and public infrastructure assessment experts to pitch the value of including non-market values in business case guidelines and discuss how the INFEWS tool could support the calculation of non-market values.
- CRCWSC participants who deliver infrastructure (e.g. state developers, utilities, LGAs) consider non-market values and trial the INFEWS tool on key projects
- Developers can use the INFEWS tools in negotiations for a fair distribution of costs where future public water sensitive benefits are unable to be recouped through housing sales.
- Identify 1-2 additional case studies in WA using the INFEWS tool.

IRP1: Deliver the Perth Transition Strategy and encourage the roll out across WA

- Support the WSTN, as required, to help implement actions in Part B (implementation plan) of the Transition strategy.
- Support the City of Perth (CoP), as required, to incorporate their transition Strategy into strategic water and land planning.
- Support the City of Bayswater, as required to incorporate their Transition Strategy into strategic water and land planning.
- Advocate and promote use of the transition strategy process to WA Regional towns and Perth Metro Local governments.
- Provide relevant information to WaterWise Councils (WWC) on how the broad range of CRCWSC tools and products can support LGAs.
- Encourage stakeholder to re-benchmark the greater Perth Metro in 2021 (first one in Feb 2016).

All IRPs: Development of appropriate research outputs and tools, readily adopted across Industry

- Key stakeholders have engaged with, and provided feedback via Project Steering committees to ensure research and products are locally and industry relevant
- Key stakeholders understand the research outputs and can adopt the knowledge across Industry

Enduring and widely used Capacity Building program

- WRAP, IRP PSC and NWW work together to prioritise and implement high impact capacity building activities related to CRCWSC outputs and case studies
- The CRCWSC website on a platform that endures beyond 2021.
- The website is user friendly and uses themed landing pages to curate and prioritise key documents

TAP1: Support the trial of the Transitions Platform with CRCWSC partners.

- LGAs undertake WSC index workshops as well as other transition components included in the Transitions Platform such as Transition dynamics Framework.

TAP2: Support the trial of the Scenario Planning Tool within the City shaping platforms with CRCWSC partners

- Maximise value from user acceptance testing by WRAP members by sharing learnings
- After release, Trial by participant organisations in relevant case studies.

Wide range of sponsors undertake Synthesis Projects across diverse issues and in diverse locations in WA

- New “Ideas for …” workshops are undertaken in Perth and across WA.
- Other synthesis processes (i.e. excluding Ideas for workshops) have been trialled in WA.
- Stakeholders value, participate in, and sponsor synthesis processes delivered by the CRCWSC and or the WSC-Institute.

Diverse range of Case studies are accessed by practitioners and provide the knowledge and confidence to undertake water sensitive projects.

- Approach partners related to potential case studies (e.g. Brabham, Subiaco, Canning and Knutsford) who may be interested in commercially sponsoring an integrated case study.
- CRCWSC and other capacity building websites illustrating case studies are linked and complement each other.
- Case studies are easy to search for via the internet.
- WA relevant case studies support participants to undertake Water Sensitive Projects.

Test the Restore Tool and design guidelines in WA

- Promote use of the RESTORE tool in at least one case studies in WA.

- WA consultants interested in trialling the tool have been provided access

The WRAP offers support to the WSTN, Waterwise Perth and other working groups with planning after the end of the CRCWSC. This includes sharing information and ideas around governance/ funding models, critical roles and activities and research focus areas.

List of Acronyms

AWA – Australian Water Association
CoI – Community of Interest
CoP – City of Perth
CRCWSC – Cooperative Research Centre for Water Sensitive Cities
DBCA – Department of Biodiversity, Conservation and Attractions
DoC – Department of Communities
DLGSCI – Department of Local Government Sport and Cultural Industries
DPLH – Department of Planning Lands and Heritage
DWER = Department of Water and Environmental Regulation
ERA – Economic Regulation Authority
EPRG – Essential Participants Reference Group
GWIG - Greywater and Wastewater Industry Group
INFEWS – Investment Framework for Economics of Water-Sensitive Cities
IPWEA – Public Works Engineers Australia
IRP – Integrated Research Project in Tranche 2
IWA – International Water Association
KATs – Knowledge and Translation
LGA – Local Government Authority
NWW – New WAter Ways (Shelley Shepherd)
PSC – project steering committee
RAP – Regional Advisory Panel
RESTORE – Optimising ecological gains to urban waterways by prioritising the natural ecosystem components for repair
REG – Regional project
RM – Regional Manager (Emma Yuen)
TAPS – Tools and products
TAPS1 – Transition Platform
TAPS2 – City Shaping Platform
TDF – Transition Dynamics Framework
TNSC-CB – Transition Network Subcommittee -Technical capacity and partnerships (Chair: Emma Monk)
TNSC-CCE – Transition Network Subcommittee - Community engagement and communications (Chair: Winsome Maclaurin)
TNSC-PG – Transition Network Subcommittee -policy and governance (Chair: Sergey Volotovskiy)
TNSC-R – Transition Network Subcommittee – research (Chair: Mike Mouritz)
UDIA – Urban Development Institute of Australia
UWA –University of WA
UAT - User acceptance testing
WALGA – Western Australian Local Government Association
WAPC – Western Australian Planning Commission
WC – Water Corporation
WRAP – Western Regional Advisory Panel
WSAA – Water Services Association of Australia
WSC – Water Sensitive Cities
WSCI – Water Sensitive Cities Institute
WSUD – Water Sensitive Urban Design
WSTN – Water Sensitive Transition Network
WWC - Waterwise Councils

CRC for
Water Sensitive Cities

Cooperative Research Centre for Water Sensitive Cities

Level 1, 8 Scenic Boulevard
Monash University
Clayton VIC 3800

info@crcwsc.org.au

www.watersensitivecities.org.au

New WAter Ways

Introducing water sensitive urban design

CRC for Water Sensitive Cities

Water sensitive tourism

Summary

The Tourism Industry in Australia is heavily reliant on our natural landscapes and beautiful beaches which are key attractions for both international and local visitors. Applying water sensitive design principles and practices at both the city and tourist development scales is critical to provide protection for water assets, enhance liveability of places and spaces and optimise use and reuse of our scarce water resources.

Introduction

Tourism is a critical economic driver in Australia. In 2019, total tourism spend (international and domestic day and overnight) reached a record $152.4 billion (Tourism Research Australia website), with sightseeing and going to the beach amongst the top activities undertaken. The importance of our natural landscapes is demonstrated by repeat visitors on holiday in Western Australia, who are more likely to spend time in our "amazing natural landscapes or national parks" and beaches than anything else (Figure 1, Tourism Research Australia, 2018). Visitors to Perth's beaches value the cleanliness and clarity of the water, the white sand, and the natural environment (Tourism WA, 2018). It is vital therefore that the quality of these important environments is protected. This can be achieved through the application of water sensitive design across our urban and natural landscapes.

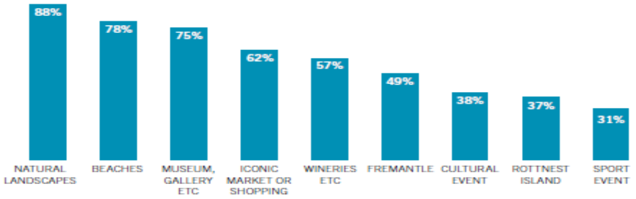


Figure 1: Activities undertaken by holiday repeat visitors on their two most recent trips (Tourism Research Australia, 2018)

How WSD supports tourism development

Water sensitive design (WSD) promotes the sustainable use, re use and management of water in all contexts across our built and natural landscapes. Protection of our important coastal landscapes is achieved through the application of WSD principles both within the catchment and coastal foreshore area which:

- create more natural environments and ecosystems;
- reduce stormwater runoff and improve flow regimes of urban waterways to reduce degradation;
- reduce pollutant and sediment loads entering freshwater and marine environments though modification to catchment drainage systems including minimising direct discharge onto beaches;
- provide protection against flooding;
- support creation of green corridors and multi-function spaces; and
- provide cooling and increased amenity of streetscapes and public areas.

Figure 2: Stormwater entering the ocean (need to replace)

Opportunities in tourism developments

Application of WSD is also critical for tourist developments, particularly as they are often undertaken in pristine environments with limited access to infrastructure. WSD can help to minimise the impact of the development on the landscape and provide a sustainable source of water through implementation of the following solutions:

- Water harvesting and reuse – including from roofs, shade structures, stormwater systems and/or local wastewater management systems. This "at source" use of alternative water supplies can also minimise energy use and increase resilience under an uncertain future climate. The level of treatment should be appropriate for the distribution and use of the source and consideration must be given to seasonal rainfall patterns, seasonal demands and storage options.
- Water efficient fixtures and fittings in buildings and for irrigation, incorporating smart technology such as weather and moisture sensors where possible.
- Capture and treatment of stormwater in vegetated swales, raingardens, biofilters or constructed wetlands which enhance biodiversity and provide cooling and amenity benefits.
- Using permeable surfaces to assist in management of stormwater and recharge of groundwater.
- Installation of a green roof on buildings to reduce stormwater discharge and provide cooling and increased amenity. Planting a green roof will also minimise visual impacts in important landscapes and increase biodiversity and habitat.
- Maintain catchment flow paths where possible through use of overland flow, directing flood flows to the environment (find a pathway to a waterway, wetland or the coast). This minimises the risks associated with over-reliance on large on-site systems with uncertain management arrangements.

Water sensitive tourism

- Retain existing vegetation and trees where possible and plant locally native species for shade, water quality treatment and ecological corridors.
- Enhance and share local knowledge including cultural values.

Figure 3: Green roof in Bondi (Atlantis Aurora) – need replacement

Case study: Rottnest Island

Rottnest Island is an A-Class nature reserve and significant tourist destination off the coast of Fremantle. Management of the island incorporates many sustainability initiatives to protect and enhance the natural landscapes, biodiversity and coastal environments which underpin the basis of the tourism economy.

Although Rottnest Island is licenced to obtain potable freshwater from a desalination plant based at Longreach Bay and the Wadjemup Aquifer, significant investment in water infrastructure has reduced the need for groundwater use and Rottnest now self-generates all the water required. This includes the use of treated wastewater to irrigate the golf course and other island landscapes. The Rottnest Island Wastewater Treatment Plant is a membrane bioreactor plant which produces consistent water quality and low pollution risk. Regular monitoring is undertaken of treated wastewater quality, irrigation and turf management practices and receiving environments to ensure performance complies with the approved nutrient irrigation and recycled water quality management plans.

Stormwater is managed simply in response to the highly permeable soils of the island through minimisation of impermeable surfaces and disconnection of catchments including un-kerbed roads. Stormwater quality risks are low as a result of a lack of sources of contamination.

The Rottnest Island Environmental Team also manage the Rottnest Island Nursery which propagate plants with island provenance used in the reforestation program. Nursery activities include seed collection, seed treatment, seed storage and propagation of seedling species native to Rottnest Island. These species are used to enhance the environment and cooling around the settlement areas.

Figure 4: The pristine environment of Rottnest Island

Case study 2??

References and resources

Rottnest Island website, 2020, Rottnest Island – About the Island – Sustainability, https://www.rottnestisland.com/the-island/about-the-island/sustainability

Tourism Research Australia, 2018, Understanding Repeat Visitation to Western Australia, Summary. Australian Government, Austrade.

Tourism Research Australia (2020) https://www.tra.gov.au/International/international-tourism-results

Tourism WA, 2018, Tourism and Perth's Coast Research conducted by Kantar Public on behalf of Tourism WA 2017/2018

www.newwaterways.org.au

New WAter Ways

CRC for Water Sensitive Cities

Introducing water sensitive urban design

Water sensitive movement networks and transport hubs

Summary

Water sensitive design promotes establishment of 'green infrastructure' and achievement of multiple outcomes, such as public amenity, habitat protection and improvement, reduced energy use and greenhouse emissions, and other outcomes that contribute to the wellbeing of Western Australians. These objectives are closely aligned with whole-of-government targets to deliver better outcomes for our citizens and environment, including through our transport networks and infrastructure.

By recognising the role WSD can play in supporting other State, regional or local objectives and promoting engagement between those responsible for planning, designing and managing our infrastructure and other relevant stakeholders, we can maximise the potential for WSD to support multiple objectives.

Introduction

Water sensitive design (WSD) promotes the sustainable use, re use and management of water in all landscapes across our built and natural landscapes. WSD can also support other relevant State, regional, and local objectives to achieve multiple outcomes, by encouraging integrated and collaborative planning and design. This includes assisting with the delivery of integrated transport solutions that are sustainable, innovative, efficient and safe.

The WA transport portfolio's Strategic Direction includes six objectives to help drive and shape the achievement of their Vision. These objectives, shown in Figure 1, are highly consistent with the objectives of WSD and integrated Water Management.

Customer focussed We keep the customer at the centre of service delivery and decision making	**Sustainable transport systems** We deliver integrated, safe, efficient transport solutions	**Innovative solutions** We innovate to optimise our service delivery and infrastructure
Planning and prioritisation We plan holistically for a growing State	**Optimising investment** We maximise the benefits of every transport dollar	**Collaborative culture** We embrace collaboration to achieve better outcomes

Figure 1: Transport Portfolio 2018-19 Strategic Direction

The delivery of WSD results in efficient, safe and healthy natural and engineered water systems. It is strongly linked to green infrastructure - the network of green spaces and water systems, like parks, streets and waterways, which makes our urban places liveable. This green network is increasingly being recognised for its critical role in enhancing the pedestrian, cycling and vehicular movement networks of our cities and spaces.

WSD in a transport context

Applying WSD principles to the development or retrofit of movement networks and transport hubs will result in multiple benefits to the community including:

- reduced amount of water transported between catchments intersected by transport networks, particularly linear systems such as road or rail corridors;
- reduced impacts on or potential improvements to the health of sensitive environments, particularly in relation to the significant areas of imperviousness and poor stormwater quality usually associated with transport corridors and hubs;
- increased water available to the community surrounding transport hubs for irrigation (via opportunities for rainwater collection, or local infiltration to the superficial aquifer);
- improved liveability around the network through increased shade, reduced urban heat, provision of additional landscape features, and increased access to the natural environment; and
- increased walking, cycling and use of public transport due to improved liveability, thus increasing cost-effectiveness of infrastructure investment, reducing congestion on roads, and reducing emissions from cars contributing to climate change.

Opportunities

Improved integration WSD into transport projects should aim to create liveability and improve the quality of the environment. Although the main interaction of transport projects with the water cycle is management of stormwater, other opportunities exist to install and operate efficient water use systems and create localised sources of water for uses such as toilet flushing or irrigation through collection of rainwater, or harvesting and treating stormwater or wastewater.

Water sensitive solutions to consider

Some WSD systems are more suitable for inclusion within a transport network than others due to their design features or maintenance requirements which may not fit within the constraints of traditional corridors and/or transport hubs. Some of the WSD solutions that are more likely to work well in movement networks and transport hubs include:

- bioretention basins, raingardens and passively watered street trees – can be designed at a range of scales and shapes and are therefore flexible in their design and location. They also provide urban cooling, increased amenity and noise reduction;
- vegetated swales – primarily due to their linear form which makes them ideally located along transport corridors;
- permeable pavement – generally suitable for light traffic areas such as roadside rest areas, car parks, depots, and pedestrian thoroughfares;
- water harvesting and reuse – including from roofs, shade structures, stormwater systems and local wastewater management systems. The level of treatment should be appropriate for the distribution and use of the source and consideration must be given to seasonal rainfall patterns, seasonal demands and storage options; and
- water efficient fixtures and fittings in buildings and for irrigation. This could incorporate smart technology and weather and moisture sensors.

WSD in movement networks (paths, roads and rail)

Linear corridors, such as those associated with footpaths, cycle paths, roads and rail lines, have the potential to impact catchment flow paths. To address this, projects for linear infrastructure should:

- maintain catchment flow paths where possible including through use of overland flow (where safety criteria can be met), culverts and bridges;
- protect important infrastructure (rail lines, significant distributor roads) from flooding and inundation – raise where necessary;

New WAter Ways

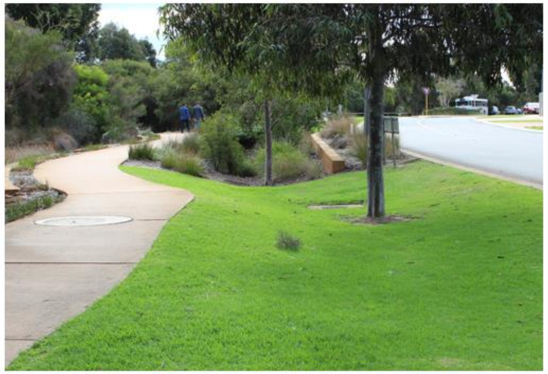
CRC for Water Sensitive Cities

Introducing water sensitive urban design

Water sensitive movement networks and transport hubs

- minimise additional impervious area - Let the water infiltrate where it falls (minimise kerbs where possible) and use vegetated flow paths to protect water quality of receiving environments, improve amenity and ecosystems;
- direct flood flows to the environment (find a pathway to a waterway, wetland or the coast). This minimises the risks associated with over-reliance on large on-site systems with uncertain management arrangements; and
- provide critical ecological links and urban cooling. Plan corridors with sufficient width for green infrastructure. Maintain existing vegetation and trees where possible and plant vegetation and trees where safe.



WSD in movement hubs (buildings and spaces)

Transport hubs such as rail/bus stations and transit-oriented development precincts also provide significant opportunity for integration of WSD solutions. These include:

- incorporating green infrastructure into buildings (green roofs, green walls, green facades) and streetscape (street trees and vegetation that receives stormwater) to improve amenity, reduce urban heat and improve environmental quality;
- use of pervious paving and disconnecting hard surfaces to reduce stormwater flows;
- harvesting rainwater from roofs or shade structures to be used in toilets;
- harvesting stormwater from hard surface areas and treated/stored in wetlands or groundwater aquifers for reuse for irrigation (subject to necessary approvals);
- upgrading existing drainage systems and reserves to form multi-purpose public open spaces and green corridors. This can provide better outcomes than excessive on-site storage requirements; and
- appropriate treatment and reuse of greywater or wastewater which can reduce need for new or upgraded infrastructure and provide an additional source of water.

Project planning and implementation

Early planning and collaboration with key stakeholders is critical to assess the feasibility of implementing different WSD systems in transport projects to ensure water sensitive and liveability outcomes are maximised. An early commitment to use of sustainability rating tools will also increase the likely performance of the project.

Application of WSD solutions should be appropriate to site conditions and development/project context.

Design considerations

Key factors requiring consideration when applying WSD to transport projects include:

- **Sensitivity of the adjacent environment** – pristine environments, threatened species/ecosystems, or drinking water catchment may require water leaving the project to be of a higher quality compared to pre-development.
- **Landform and geology** – overall topography of the land through and soil types of the site will determine which WSD systems are best suited to the project site.
- **Effective imperviousness** –understand the change in imperviousness resulting from the project, and thus additional runoff requiring management compared to pre-development.
- **Space and layout** –availability for appropriately sized WSD systems, including linear corridors (roads/footpaths/railway lines) and hubs (train & bus stations/car parks/airports)
- **Project-specific objectives** – do stakeholders require particular outcomes (e.g. providing a source of irrigation water as well as encouraging public transport use and managing flooding)
- **Safety** – an understanding of safety issues when incorporating WSD for both asset user and maintenance.
- **Maintainability** – the ability and capacity of the final asset owner to maintain the WSD systems.
- **Cost-benefit** –whole-of-life cost (capital and operational cost) of incorporating different WSD systems into a project versus multiple benefits.
- **Legislative or policy obligations** – any Local, State or Federal planning or legislative instruments, or any internal or external requirements (e.g. GBCA Green Star rating).




Case study: Northlink WA

NorthLink WA, a $1.02 billion road project connecting Morley and Muchea, demonstrated the benefits of applying a WSD approach to the management of stormwater. The vision for the major project, led by Main Roads WA, included a desire to maximise sustainability though economic, social and environmental responsibility.

The emphasis on sustainability was cemented early in the project though the requirement to achieve an Excellent Infrastructure Sustainability rating from the Infrastructure Sustainability Council of Australia (ISCA) in the Request for Proposal.

The project team demonstrated a strong culture for improved project outcomes. Key WSD strategies included water sensitive stormwater management and water conservation and efficiency. The drainage strategy incorporated strings of drainage basins planted to mimic the natural wetland chains in the area. The project resulted in a net gain in the area of native vegetation through the planting of over 3 million trees and more than 1000kg seed. The NorthLink WA Southern Section achieved a 24% reduction in water use through innovative materials selection and use of drought tolerant plant species which designed out the need for reticulation in most areas. It also achieved a 10% reduction in the cost of pit and pipe systems and associated fencing (nearly

$700,000 saving) through infiltration at source, which also lead to smaller basins.

The NorthLink WA Southern Section achieved the highest ISCA design rating score in WA (93). It also won the IS Impact Award (projects > $20M) and Outstanding Achievement Award from ISCA in 2017.

References and resources

Department of Transport, Main Roads WA, Public Transport Authority, 2019, *Connecting People and Places: Transport Portfolio 2018-19*.

NSW Transport Roads and Maritime Services, 2017, Water sensitive urban design guideline: Applying water sensitive urban design principles to NSW transport projects.

New WAter Ways

CRC for Water Sensitive Cities

Introducing water sensitive urban design

Water sensitive design supports healthy communities

Summary

The health and liveability of communities is inextricably linked to water. In addition to restoring the hydrological cycle and improving surface and groundwater quality in our urban areas, the health benefits of investing in Water Sensitive Design to improve the liveability of communities has been increasingly recognised. Incorporating water sensitive solutions into our infrastructure, buildings, streets and public spaces provides key health benefits including:

- cooling of the local environment to reduce urban heat;
- improved amenity of streets and built form;
- more green spaces available to the public for recreation and play;
- increased connections to nature and green space to improve mental health.
- improved air quality;
- sustainable irrigation; and
- increased sense of community and liveability.

Investing in the improvement of the health and wellbeing of the community has flow on economic effects by reducing pressure on the public health system and improvements in work efficiency.

Introduction

Health systems are designed to deliver safe, high quality and accessible services that focus not only on treatment but also prevention, to increase the general level of health across the community, contributing to wider social and economic benefits for the community (Department of Health, 2015). This focus on multiple outcomes is also at the heart of water sensitive design, which aims to optimise management of water resources and the water cycle to support delivery of social, environmental and economic benefits.

Vision

To deliver a safe, high quality, sustainable health system for all Western Australians.

Values

WA Health's Code of Conduct identifies the values that we hold as fundamental in our work and describes how these values translate into action.

Our values are:

Quality Care | Respect | Excellence
Integrity | Teamwork | Leadership

Vision and Values of the WA Department of Health

How WSD supports a healthy community

Water sensitive design promotes the sustainable use, re use and management of water in all contexts across our built and natural landscapes. Application of water sensitive design results in more natural water cycles and improved water quality, which leads to healthier environments and ecosystems. However, recognition is increasing regarding the benefits of water sensitive design to the physical and mental health of our communities.

The health benefits to our communities from water sensitive design include:

- increased access to nature which improves mental well-being and provides opportunities for passive recreation (WHO, 2016);
- urban cooling from green roofs, green walls, vegetated stormwater systems, passively watered street trees, waterways, wetlands, and irrigated parks;
- improved amenity provided by the visual appearance of green infrastructure;
- access to sustainable sources of water for irrigation of active recreation spaces;
- increased usage of pathways for walking and cycling when these are integrated with green and/or blue infrastructure;
- reduced numbers of mosquitoes and midges through creation of healthy ecosystems;
- improved air quality through reductions in noise, light and pollutant levels from interaction with vegetation; and
- enhanced sense of community (socialisation and connections between individuals) where management of waterways and wetlands is undertaken by community members.

Drivers for WSD in our communities

There are a number of drivers for the integration of water sensitive design into our communities. These include:

- the multiple health benefits of local and easily accessible green spaces to the community are increasingly being recognised and valued by the community;
- lack of available water and increasing water restrictions and/or uncertainty around water availability makes the provision of accessible green spaces increasingly difficult;
- densification and infill in urban areas reduces amenity and space for greening and also increases pressure on available green spaces; and
- climate variability leading to increasing temperatures and flashier flooding requires solutions that promote resilience.

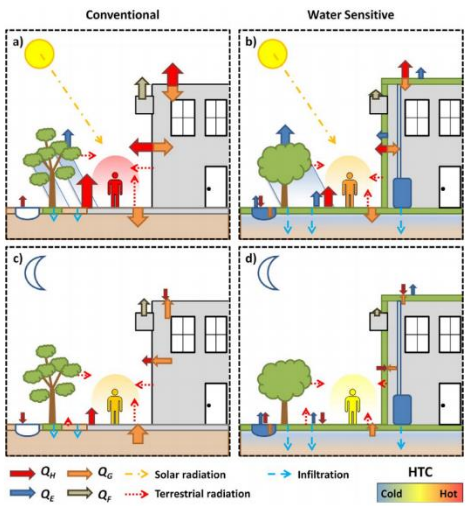


Figure 1: WSUD systems support a reduction in surface radiative temperatures thereby improving human thermal comfort (Source: Coutts et al. 2012)

New WAter Ways

Introducing water sensitive urban design

Water sensitive design supports healthy communities

www.newwaterways.org.au

CRC for Water Sensitive Cities

Opportunities

Water sensitive design opportunities which improve mental and physical health can be incorporated into all elements of our cities, including neighbourhoods, streets, parks (including drainage infrastructure) and buildings.

Water Sensitive Neighbourhoods

Urban forestry programs which promote increased planting of trees, particularly where the trees are passively watered by diverting stormwater systems (CRCWSC, 2020).

Opportunities for celebration of cultural values, particularly as many Aboriginal values are associated with water.

Water Sensitive Parks

Passively directing flood flows to parks.

Planting trees and irrigating parks with groundwater or recycled water (can reduce temperatures in surrounding area by 1-2 degrees, Coutts et al, 2015).

Retrofitting drains and detention basins into vegetated areas for public access and connections.

Areas downwind of waterbodies are cooler than other areas.

Water Sensitive Streets

WSUD system vegetation and shading from trees can cool streets by up to 6 degrees in comparison to streets without trees (Coutts et al, 2015).

Passively watered trees grow faster than those without access to stormwater.

Street trees increase neighbourhood amenity and property values (Plant et al. 2017; Pandit et al 2013).

Street trees can cause motorists to drive slower (Naderi, et al, 2006, 2008, Edquist et al 2009).

Water Sensitive Buildings

Green walls and green facades improve amenity; reduce external and internal building temperatures; and can be watered via local greywater systems.

Green roofs assist in stormwater management and provide biodiversity and amenity benefits. Green roofs can reduce surface temperatures by up to 20 degrees (Coutts et al, 2013). Green roofs can fit on any podia and can be watered from greywater (e.g. WorkZone offices, Perth).

Permeable driveways lower surface temperatures, improve stormwater management and increase amenity though opportunities for greening.





Considerations

The degree of health benefit depends on multiple factors and it is important to also recognise the other environmental and economic benefits that occur from implementing water sensitive design strategies. Choosing the most appropriate water sensitive design approach to promote health benefits requires consideration of:

- community values – who is likely to use the area? What do they value? Can the project build community support for and knowledge of water sensitive design?
- environmental conditions – respond to site climate conditions, protect important environmental values and incorporate locally native vegetation species.
- site conditions – solutions must be appropriate to soil type and landform.
- site context – consider form, function and scale of application. How much space do you have? How will your solution enhance the site's character?
- water sources and the water cycle. How much water do you need and for what purpose? Is it seasonal? What sources of water are available?
- maintenance requirements - How much will it cost to maintain? Are any particular skills required?
- Approvals - Are there any regulatory or reporting requirements? Is support provided by any strategy or policy? What design guidelines are available?

References

CRCWSC, 2020, Designing for a cool city–Guidelines for passively irrigated landscapes. Melbourne: Cooperative Research Centre for Water Sensitive Cities.

Coutts, A. Tapper, N. Loughnan, M. Demuzere, M. Broadbent, A. Motazedian, A. White, E. Phan, T. Thom, J. Gebert, L. Pankhina. D., 2015, Determine the microclimatic influence of harvesting solutions and WSUD at the micro-scale: Presented as Frequently Asked Questions. Melbourne, Australia: Cooperative Research Centre for Water Sensitive Cities.

Coutts, A.M., Daly, E., Beringer, J. and Tapper, N.J., 2013, Assessing practical measures to reduce urban heat: Green and cool roofs. Building and Environment, 70:pp. 266–276.

Department of Health, 2015, WA Health Strategic Intent 2015 – 2020, Government of Western Australia.

Introducing water sensitive urban design

Water sensitive design supports healthy communities

Edquist J, Rudin-Brown, C.M. and Lenne, M.G., 2009, Road Design Factors and their Interactions with Speed and Speed Limits, Monash University Accident Research Centre.

Frontier Economics 2019, ‘Health benefits from water centric liveable communities’. A report prepared for the Water Services Association of Australia.

Naderi, J, Kweon, B and Maghelal, P. 2006, Simulating Impacts of Curbside Street Trees on Driver Performance and Perception, Transportation Research Board.

Naderi, J, Kweon, B and Meghelal, P. 2008, The Street Tree Effect and Driver Safety, ITE Journal on the Web, pp. 69-73.

Pandit, R., Polyakov, M., Tapsuwan, S. & Moran, T. 2013. The effect of street trees on property value in Perth, Western Australia. Landscape and Urban Planning, 110, 134-142.

Plant, L., Rambaldi, A. & Sipe, N. 2017. Evaluating Revealed Preferences for Street Tree Cover Targets: A Business Case for Collaborative Investment in Leafier Streetscapes in Brisbane, Australia. Ecological Economics, 134, 238-249.

WHO, 2016, Urban green spaces and health. Copenhagen: WHO Regional Office for Europe, 2016

COOPERATIVE RESEARCH CENTRE FOR WATER SENSITIVE CITIES

EXPERT PANEL ON URBAN DEVELOPMENTS IMPACTED BY HIGH GROUNDWATER

FINAL REPORT CONTAINING INITIAL GUIDANCE AND RECOMMENDATIONS FOR FUTURE RESEARCH AND OTHER WORK

MARCH, 2020

Acknowledgements
The Expert Panel acknowledges and thanks those people who met with Panel members and participated in discussions to provide practitioner and researcher perspectives and insights about urban developments in areas of the Swan Coastal Plain of Western Australia impacted by high groundwater. Information and knowledge from participants and feedback from stakeholders in the Expert Panel's project have provided key inputs to this Final Report. However, the Expert Panel takes full responsibility for the content of this Final Report, which invariably from time to time also includes some of our interpretations of what we have "seen and heard".

Table of contents

Executive Summary 4
Key Findings 4
Key Guidance 6
Key Recommendations for future research and other work 7
1. Background 9
1.1. Reason for this Expert Panel Project 9
1.2. Methodology 10
1.3. Scope of this report 11
2. Introduction 11
2.1. What is high groundwater? 11
2.2. Why can high groundwater be a problem? 12
2.3. Understanding high groundwater: the pre- and post- urban development water balances 12
2.4. Current development responses to high groundwater and their implications 14
3. Terminology 17
4. Guidance 18
4.1. Cumulative impacts of development 18
4.2. Site-based risk assessment 21
4.2.1. Guidance regarding CGL assessments 24
4.2.2. Guidance regarding one-dimensional groundwater model assessments 25
4.2.3. Guidance regarding 2-D / 3-D groundwater assessments 27
4.2.4. Inherent limits of model certainty 28
4.3. Design to minimize fill and/or waterlogging risks 28
4.4. Assessing performance 29
4.5. Available guidelines 29
4.6. Approaches to standardise aspects of modelling and design review 30
4.7. Capacity building and advice 30
4.8. Legal frameworks 31
4.9. Changing building practice and behaviour 31
4.10. Changing the planning, building and construction approval processes 31
4.11. Recovery of groundwater drainage waters 32
4.12. Performance of WSUD in high groundwater environments 32
4.13. Off-site impacts of fill on hydrology, hydroperiod and ecology 32
4.14. Clarity of geo-technical investigations and options 32
4.15. Transparency and coherence in technical reports 33
5. Recommendations for future research or other work 33
5.1. Improve understanding of recharge dynamics of the pre- and post-development landscapes at a range of scales 34
5.2. Improve understanding of the risks associated with common modelling assumptions 35

5.3. Develop tools to facilitate Local Government assessment of proposals 35
5.4. Proceed towards the creation of demonstration projects 36
5.5. Cooperatively develop further guidance 36
6. Summary and conclusions 36
7. References 38
Appendices 40
Appendix A. Expert Panel Terms of Reference 41
Appendix B. Expert Panel Methodology 43
Appendix C. List of questions for participants 44
Appendix D. Summary of literature 47
Appendix E. Examples of international approaches to manage high groundwater in urban areas. 55
Appendix F. Summary of inputs from practitioners and researchers 65
Appendix G. Glossary of Terms 69

Executive Summary

The Cooperative Research Centre for Water Sensitive Cities (CRCWSC), in collaboration with research and industry partners, has been progressing Integrated Research Project Five (IRP5 - *Knowledge based water sensitive solutions for development in high groundwater environments*) (CRCWSC, 2017). As part of Stage 2 of IRP5 - *Guiding urban water management in areas of the Swan Coastal Plain that experience high seasonal groundwater* – the CRCWSC established an Expert Panel in September, 2019 to prepare two main products:-

1. Technical guidance for planning and designing urban developments in high groundwater areas, building on practitioners' and researchers' experience and knowledge of the Swan Coastal Plain in Western Australia; and
2. Recommendations for further research, data and information collection and/or methods that may improve the guidance over time.

The Expert Panel consisted of Assoc Professor Dr Sally Thompson from the University of Western Australia (UWA, Perth), Dr Margaret Shanafield from the National Centre for Groundwater Research and Training (NCGRT, Flinders University, Adelaide), and Greg Claydon (Chair, CRCWSC Board Director), assisted by Research Associate Dr Ana Manero Ruiz (UWA, Perth).

It has produced this Final Report based on site visits, detailed discussions with and feedback on an earlier Draft Report from a range of Western Australia based urban development industry practitioners and consultants, local and state government officials and researchers, and consultation with the Urban Development Industry Association's (UDIA) Water Committee for WA, the multi-stakeholder Land Development in Groundwater Constrained Environments Steering Group (convened by the Institute of Public Works Engineering Australasia (IPWEA) WA branch and the Western Australian Local Governments Association - WALGA), the CRCWSC's Western Region Advisory Panel and Perth's Water Sensitive Transition Network. This Report also draws on relevant previous work by the CRCWSC and the Expert Panel's own tacit knowledge and experiences.

(Note that we have used the term "high groundwater" throughout this Report, recognizing that this is the standard terminology used by the CRCWSC for IRP5. However, we recognise that the term "shallow groundwater" is also used in the literature and by some practitioners and researchers, perhaps to potentially help illustrate the importance of surface water and groundwater interactions and what happens in the unsaturated zone between the two, and recognising that, in groundwater management generally, groundwater levels may be relatively "high" (e.g. after relatively higher rainfall periods) but not "shallow")

Key Findings

[1] Changes to the status quo can bring benefits - The status quo for predicting and mitigating the impacts of high groundwater on urban development is generating harm in several areas of urban development and sensitive environments within the Swan Coastal Plain of Western Australia. Uncertainties in the status quo approaches have, in some instances, led to using excessive amounts of on-site sand-based fill, which add to urban development costs and impact housing affordability. In other instances, insufficient mitigation of high groundwater has led to nuisance flooding, damage to public and private infrastructure, water quality deterioration and changes to groundwater dependent ecosystems. This means that adoption of best practices or changes in the development methods could present a win-win-win opportunity for the public, the environment, and for land development interests.

[2] There is a need for better technical guidance on and understanding of the urban water balance - Currently, limited sector-wide technical guidance exists to predict the impact of urbanisation on water balances and water quality in specific areas constrained by high groundwater, although industry practitioners have been working together over recent years to identify and fill knowledge gaps and

promote best practices. The success of these efforts has been hampered by data, information, process, regulatory and capacity barriers.

[3] Earlier decision making in the planning and approval processes can mitigate cumulative adverse impacts - Land development in high groundwater areas may have cumulative environmental impacts, for example on flooding, water quality and/or on the health of groundwater dependent ecosystems (GDEs). Such cumulative impacts need to be identified and managed early in the planning and approval process. Early identification and management are, more often than not, at odds with the current timing and scale of detailed hydrological site assessments, which typically occur at subdivision scale, in the framework of a local water management plan, and *after* regional and district planning decisions have been taken.

[4] Different approaches are required for different levels of groundwater risk - In developing local water management plans and subdivision-scale engineering designs, the appropriate level of site investigation, modelling and design varies with site-specific groundwater "risk". Consequently, depending on the site risk, there may be differences in the extent of monitoring needed to inform modelling for planning and design, in the types of assumptions that should be made in modelling and design, and in the extent and transparency of the information used to prepare reports for approval.

[5] Technical demands on Local Governments are significant - The demands in terms of time and personnel on Local Governments imposed by the review and approval of technical hydrological/hydrogeological/engineering investigations and designs are significant. Maximising Local Governments' abilities to meet these demands is a key opportunity to improve development outcomes in high groundwater environments across the Swan Coastal Plain.

[6] Lack of clarity around governance responsibilities can present barriers to good technical results - Breaks in the chain of responsibility within the planning, design and construction process contribute to failures to achieve best practice outcomes. These can be exacerbated by:

- Separation of responsibilities within state and Local Government departments;
- Lack of clear and open channels of communication between Local Government decision-makers and advisory state departmental bodies;
- Inconsistent requirements for assessing proposals across municipalities.

[7] Several other barriers need to be overcome to satisfy the appetite for greater innovation - Diverse stakeholders are calling for greater innovation in construction methods/materials, stormwater management, allocation of responsibility between private and public entities, and in the planning process more broadly. Roadblocks hindering such innovation include:

- Lack of timely post-development monitoring;
- Lack of guidance informing how to implement innovations and consider trade-offs;
- Lack of well-monitored demonstration sites;
- Legal ambiguity around the status of and responsibility for drainage infrastructure, particularly on private lots;
- Fragmented and incomplete legal frameworks around surface and sub-surface drainage management;
- Late introduction of detailed hydrological assessments within the planning and approval processes (particularly problematic for cumulative impact mitigation), despite the existence of the Better Urban Water Management framework (WAPC, 2008).

[8] Better use can be made of existing and future monitoring information - Improving the timeliness of post-development monitoring, and making better use of the information generated by such monitoring, will have several benefits:

- Creating opportunities for adaptive management (given that the development cycle for a given subdivision may proceed over 1-2 decades, earlier monitoring would create an opportunity to rectify any design flaws);
- Greatly adding to the data, information and knowledge available about the spatial and temporal impacts of urban development on water balances, levels and qualities in locations subject to high groundwater; and
- Better informing future planning and design and improving long-term outcomes for the industry, community and the environment.

There are positive opportunities for industry, regulators and academia to work closely together towards this additional knowledge building.

While the Expert Panel acknowledges that some of the above findings are arguably outside of the scope of our Terms of Reference (Appendix A), we nevertheless see them as important and there is a need for progress to be made in addressing them.

Key Guidance

[1] <u>A risk-based framework</u> - Guidance is provided for adopting a consistent, risk-based framework to determine the level of pre-development site investigation, modelling and design evaluation that is appropriate for locations impacted by high groundwater. This framework is based on evaluation of the annual exceedance probabilities (AEPs) for the level of the phreatic surface, and includes:

- The use of simplified (and potentially further improved) Controlled Groundwater Level (CGL) methods for <u>low-risk sites</u>;
- One-dimensional modelling methods (e.g. those based on the Hooghoudt equation) with enhancements for <u>moderate-risk sites</u>;
- Two- or three-dimensional modelling methods (as the default without very strong justifications otherwise) for <u>high-risk sites</u>.

These levels of risk are based on factors such as pre-development groundwater level (depth), pre-development land use/water quality, pre-development groundwater abstraction, soil type, receiving environments and other environmental constraints. Note that (i) this framework is intended to provide guidance only, and should be subject to site-specific consideration of appropriate levels of assessment, developed between regulators and proponents, and (ii) the use of the term “annual exceedance probability” in this context does not refer to storm-event AEPs, but to AEPs developed based on long-term monitoring or modelling of water table levels.

[2] <u>Consistent and coherent modelling approaches</u> - In using the risk-based framework, consistency is required in modelling work and assumptions across the various planning levels and stages, with appropriate sensitivity analyses undertaken, and controls in place to ensure that the assumptions and results can be followed through to implementation. Guidance is provided for a limited number of key influencing parameters, including for assisting initial “sense” checks, while recognising the importance of appropriate site-based and case-based methodologies. Where deviations in modelling or assumptions, including parameter values, from earlier work are to occur or have occurred, justifications should be coherent, transparent and supported, with any associated additional risks and cumulative impacts clearly identified.

[3] <u>Demonstration of robust and resilient design and construction approaches</u> - An alternative approach to further refining modelling is to adopt lot/sub-division/precinct/drainage designs that can accommodate modelling error and/or other uncertainties. Various approaches are available and are being used or considered by experienced practitioners in WA. These should be the subject of further demonstration and monitoring to evaluate their performance.

[4] Development and use of helpful technical assessment tools - Local Governments should adopt tools to facilitate their approval and compliance roles. These could include adopting existing or new/updated guidelines/approaches or parts thereof, checklists, identification of "red flags" that indicate potential modelling or design problems, or numerical tools. State regulators should be involved in the development and adoption of these tools to ensure consistency and coherence, and the urban development industry and their consultants should be involved in their preparation and assisting in their dissemination.

Key Recommendations for future research and other work

Research and/or other work should be undertaken to:-

[1] Improve understanding of recharge dynamics of the pre- and post-development landscape at a range of scales by:

- Measuring (and parameterising models to predict) evaporation and transpiration from un-developed landscapes with high groundwater, (and making these models available to stakeholders, including consultants, developers, agencies, and Local Governments for prediction purposes);
- Measuring gross recharge associated with different components of the urban landscape (including lot rears, soakwells and paved areas), under different soil and depth-to-water conditions;
- Developing methods to predict gross and net recharge across the range of urban landscape components, soil types and depths to water;
- Further considering future climate impacts on recharge dynamics;
- Further considering water quality impacts; and
- Considering research that would develop/assess new and innovative technologies/methods to measure aspects of the urban water balance, that are more accurate, more practical, cheaper, more reliable, and/or more suited to urban systems than currently exist.

It is acknowledged that while the above priority knowledge gaps should be progressed, research in this area will be of limited benefit if it is not well understood how changes to the local hydrology (including water quality) will impact on the receiving environments or adjacent environmental assets. This underlying need is fundamental to the protection of Western Australia's environmental assets and should be a consideration in all stages of research, modelling, legislative approvals and development.

[2] Improve the understanding of the risks associated with common modelling assumptions, in particular those associated with the use of steady state models such as the Hooghoudt equation. Issues to be addressed include:

- Viability of replacing steady state models with quasi-steady models and the errors in AEP computation associated with such replacement;
- Techniques to select appropriate cross sections on which to apply a Hooghoudt equation when subsoil drains are graded and the perpendicular lengthscale is an underestimate of actual flow path length
- Assessment of whether parameter values for recharge and saturated hydraulic conductivity in the Hooghoudt equation introduce larger uncertainties than the actual physical setting of the subsoil drains.

[3] Develop tools to facilitate the technical assessment of proposals by Local Governments and provide education and training in the use of those tools, up-to-date guidance materials and other matters relevant to building industry and regulator capacity, institutional strengthening and capability.

[4] Proceed towards the creation and evaluation of demonstration projects on topics including:

- Alternative construction methodologies and urban and built forms appropriate to high groundwater environments,
- The performance of a variety of precinct, sub-division, and on-lot stormwater management strategies,
- The feasibility of rear-of-lot directly connected drainage of the local groundwater mound; and
- Landscaping approaches that are compatible with high groundwater in lot rears and in public open spaces.

[5] Expand on the work of this project to cooperatively develop a comprehensive technical guidance note, supported by the urban development industry and regulators, for planning and designing urban developments in high groundwater areas. Such guidance could be incorporated into existing processes and documents, such as those associated with *Australian Rainfall and Runoff 2019*, and/or build on those of the IPWEA, noting, for example, that IPWEAWA has produced a *Specification for separation distances for groundwater-controlled urban developments 2016*. The guidance note could usefully include a short series of case studies and worked examples to help explain a methodology and why it is reasonable in each particular case. Such a guidance note could also be used to inform and, for relevant parts, be incorporated into initiatives such as Design WA, currently being developed by the Western Australian Planning Commission.

Note that, while the above priority list can sensibly be undertaken in the order presented, it can also be progressed iteratively as resources and circumstances permit. It is not a comprehensive list of all technically related research needs, nor does it cover specific improvements in commercial, legal and planning frameworks surrounding urban development in high groundwater environments, which were beyond the brief for the Expert Panel. We encourage stakeholders to explore the policy issues and options identified in this report, including greater legislative clarity, to reduce or remove barriers to the implementation of otherwise sensible technical solutions. It is the considered view of the Expert Panel that addressing the policy, regulatory and governance issues identified in this report will lead to better informed decision making, mitigation of unacceptable risks and better environmental, economic and liveability outcomes.

Without progress in the above areas of research and further work, and the development and following of improved guidance, we believe that impacts of high groundwater will continue to generate harm in several areas of urban development and sensitive environments within the Swan Coastal Plain. These harms include (a) the use of excessive amounts of on-site sand-based fill, which adds to urban development costs, impacts housing affordability, and creates environmental impacts including quarrying, transport/carbon costs, sedimentation/erosion risks, and long term changes in the landscape profile; and (b) insufficient management of the risks posed by groundwater which can lead to nuisance flooding, public health risks (e.g. mosquito breeding) and damage to public and private infrastructure in at-risk locations.

Although challenges remain in managing development in high groundwater environments, the Expert Panel was tremendously impressed and heartened by the commitment, goodwill and engagement of a very broad suite of stakeholders in addressing these challenges. We hope that this Report forms a useful contribution to minimising risks to the built and natural environments, and to maximising the opportunities for innovation, resource recovery and creativity that the challenge of high groundwater also provides.

1. Background

1.1. Reason for this Expert Panel Project

Western Australia established a process in 2008 to consider water resources as part of the planning and development approvals system (WAPC 2008). When managing high groundwater, a local structure plan requires estimation of current and future groundwater levels, as well as the potential for the development to mobilise groundwater nutrients and contaminants. To date, particular guidance has been provided for the development of district water management strategies, local water management strategies and urban water management plans – Figure 1 (Department of Water 2008), and for the control of groundwater levels (Department of Water 2013).

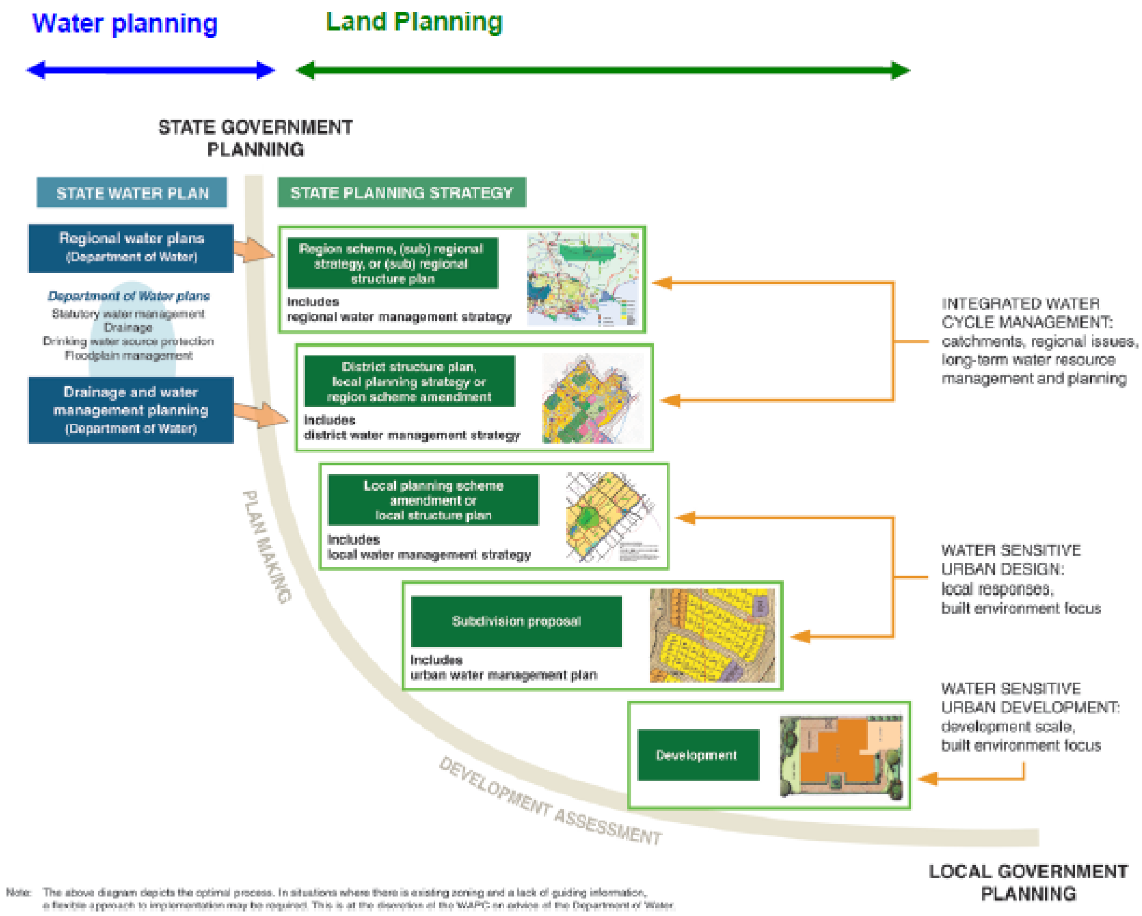


Figure 1 Integration of land and water planning in Better urban water management

In response to these requirements, the practitioners in WA make assumptions to predict:

- changes to groundwater levels post development;
- runoff and recharge rates under different conditions for stormwater management; and
- interactions between surface water and groundwater.

Currently these predictions are based on available guidelines, including those by *Australian Rainfall and Runoff* (Ball et al. 2019) and the Institute of Public Works Engineering Australasia (IPWEA 2016). Despite significant scientific advances in the area of urban developments in locations impacted by high groundwater (Barron et al, 2013; Ocampo et al, 2017; Ocampo, 2018), there is still debate among WA water management practitioners about the accuracy of certain approaches and assumptions for modelling and management of high groundwater environments in the Swan Coastal Plain. This has implications for achieving best practice urban development in such environments, now and in the future. As a result, there is a need for a consistent approach in the Swan Coastal Plain to determine appropriate water management strategies for urban development in such environments.

In response to such a need, the Cooperative Research Centre for Water Sensitive Cities (CRWSC) established two projects. The first one (2014-2018), *Hydrology and nutrient transport processes in groundwater/surface water systems Project B2.4*, aimed to assess the performance of source control systems (SCSs) in areas impacted by high groundwater (CRCWSC 2019). Further, in 2017, the second project was launched: *Knowledge-based water sensitive city solutions for groundwater impacted developments* – also referred to as Integrated Research Project Five (IRP5) (CRCWSC 2017).

IRP5 consists of two stages. The aim of Stage 1 (conducted mostly in 2018) was to better understand the impact of urban development in areas of high groundwater, with a focus on the Swan Coastal Plain. Following a review of the literature and stakeholder interviews, the Stage 1 Report (GHD 2018) identified over 30 specific questions where current understanding is lacking or inconsistent among experts and practitioners. These questions were grouped into four key areas of knowledge regarding pre- and post-development water balance: 1) Infiltration and recharge rates; 2) Evapotranspiration rates; 3) Groundwater fluxes; and 4) Groundwater levels. Areas (1) and (2), together with post-development pollutant pathways and nutrient cycles, were prioritised to be addressed in Stage 2 of IRP5.

Thus, Stage 2 was commissioned in 2019 to address the knowledge gaps identified in Stage 1. Stage 2 is structured in two activities: an Expert Panel guidance note and field validation of recharge parameters. The Expert Panel was established to formulate guidance for the concept planning and design approach to be applied when developing water management strategies for urban development in high seasonal groundwater environments (see Appendix A for the Expert Panel's Terms of Reference). The principal objective of the guidance is to provide consistent methodology for designing urban developments in areas subject to high seasonal groundwater tables.

This Final Report synthesizes the understanding developed by the Expert Panel about best practice methodology for technical assessment and management of high groundwater in urban development sites, and provides guidance as to how this best practice could be standardised.

1.2. Methodology

The understanding and guidance provided in this Final Report are based largely on-site visits and information provided by academia, industry and government representatives through presentations to and discussions with the Expert Panel in November and December 2019 and February 2020. Participants were asked to present about the details of site assessment, modelling and design undertaken in one or more projects in which high groundwater was an important technical constraint on urban development. A detailed description of the methodology is presented in Appendix B. Participants were provided with a list of technical questions (Appendix C) by the Expert Panel, noting that not all of the listed questions were relevant in every instance. Following any presentations, the Expert Panel undertook semi-structured discussions with the presenters.

The Expert Panel has also drawn on relevant literature from Australia and overseas and previous work by the CRCWSC, together with its own tacit knowledge and experience.

Additionally, the Expert Panel, or members thereof, consulted on an earlier Draft Report with several relevant stakeholder groups, including the Urban Development Institute of Australia (UDIA) Water Committee for WA, the multi-stakeholder Land Development in Groundwater Constrained

Environments Steering Group (convened by the Institute of Public Works Engineering Australasia (IPWEA) WA branch and the Western Australian Local Governments Association - WALGA), the CRCWSC's Western Region Advisory Panel and Perth's Water Sensitive Transition Network, and reported to the CRCWSC's IRP5 Project Steering Committee.

1.3. Scope of this report

The Expert Panel's role is to provide guidance and recommendations for future work pertaining to best practice around technical issues - for example those relating to fundamental scientific uncertainty, uncertainties derived from model representation of hydrological processes in areas impacted by high groundwater on the Swan Coastal Plain and within corresponding areas of urban development, and uncertainties associated with the parameterisation of such models. Policy, governance and planning questions that pertain to the ability of developers and their consultants to undertake best-practice technical site assessment, water related modelling and associated engineering design, and of decision-makers to approve, modify or reject corresponding technical elements of proposed development plans, were treated as lying within the scope of the Expert Panel.

The Expert Panel recognises that many stakeholders see a very broad scope for improvements in the commercial, legal and planning frameworks surrounding urban development in WA and likely elsewhere. These broader topics, however, lie beyond the brief of the Expert Panel. We have attempted to reflect and recognise these issues as they were raised to the Expert Panel (see Appendix F for a summary of inputs from practitioners), but do not provide specific guidance relating to these broader topics.

The Expert Panel's review was limited to the material and information with which we were presented and the related discussions. This also constrains our ability to offer guidance on all pertinent topics. For example, where only a single participant addressed a topic, we may have lacked a sufficient weight of evidence to elucidate what 'best practice' would consist of. The guidance we provide in these topics is necessarily high level - even though several of these topics are of great urgency and importance. Further, several issues, considered important by the Expert Panel, were not raised by any participants (likely due to the relevant people not engaging with the process). In these cases, we identify that we believe that technical concerns do exist with reference to these topics, but again generally refrain from providing specific guidance - even though, again, these topics may be of urgent importance.

2. Introduction

2.1. What is high groundwater?

For the purposes of this Report, the Expert Panel has adopted high groundwater regions as those in which the top of a perched water table or an unconfined aquifer (the water table or phreatic surface) regularly approaches the land surface, e.g. groundwater within 0.9 m of the surface (Minnesota Stormwater Manual contributors 2019), or within 4 m of the surface in IRP5 Stage 1. For consistency with IRP5 Stage 1, if the phreatic surface is within 4 m of the land surface, we are saying the location has "high groundwater". (Note that we have used the term "high groundwater" throughout this Report, recognizing that this is the standard terminology used by the CRCWSC for IRP5. However, we recognise that the term "shallow groundwater" is also used in the literature and by some practitioners and researchers, perhaps to potentially help illustrate the importance of surface water and groundwater interactions and what happens in the unsaturated zone between the two, and recognising that, in groundwater management generally, groundwater levels may be relatively "high" (e.g. after relatively higher rainfall periods) but not "shallow".)

High groundwater regions occur worldwide, including in regions with shallow confining layers, montane and piedmont areas, floodplains, deltaic environments and lowlands more generally (see

Figures D1 and D2 in Appendix D). In Australia, high groundwater environments are prevalent in the south west of the country, along the foothills of the Great Dividing Range, in parts of the interior, and along river floodplains (Fan et al, 2013). This Report focuses on high groundwater on the Swan Coastal Plain that surrounds and contains the Perth metropolitan area. Figures D3 and D4 (in Appendix D) illustrate the spatial distribution of depth to groundwater in the Swan Coastal Plain and its overlap with planned future urban growth.

2.2. Why can high groundwater be a problem?

Urban development moving into areas impacted by high groundwater results in challenges for industry, planners, regulators, the general community and the environment.

High groundwater has the potential to cause several impacts (GHD et al, 2018; New WAter Ways, 2019) including:

- damage to infrastructure, including concrete foundations and bitumen roads, with possible structural failure;
- compromised performance of water (and "wastewater") control systems;
- loss of amenity in public and private open spaces, with seasonal or event-based water logging preventing pedestrian or vehicular traffic; and/or restricting sustainable plant growth or health; and/or potentially creating conditions for mosquito and nuisance midge breeding;
- increased amounts of poor-quality water entering receiving waterways and wetlands.

Nevertheless, high groundwater can also present opportunities. For example, there is a focus on increasing urban tree canopy in the Perth metropolitan area for multiple benefits, including urban cooling and enhanced liveability. Access to groundwater provides a source for vegetation establishment and reducing irrigation requirements. The opportunity of using high groundwater as a supply source is discussed later in this Report.

2.3. Understanding high groundwater: the pre- and post- urban development water balances

Determining and understanding pre-development groundwater levels and their fluctuations is a critical component of urban planning, design and management (New WAter Ways, 2019). The pre-development water balance is influenced by rainfall, interception, evapotranspiration, infiltration and runoff characteristics, while geotechnical and hydrogeological factors also influence recharge into an aquifer (see Figure 2 below).

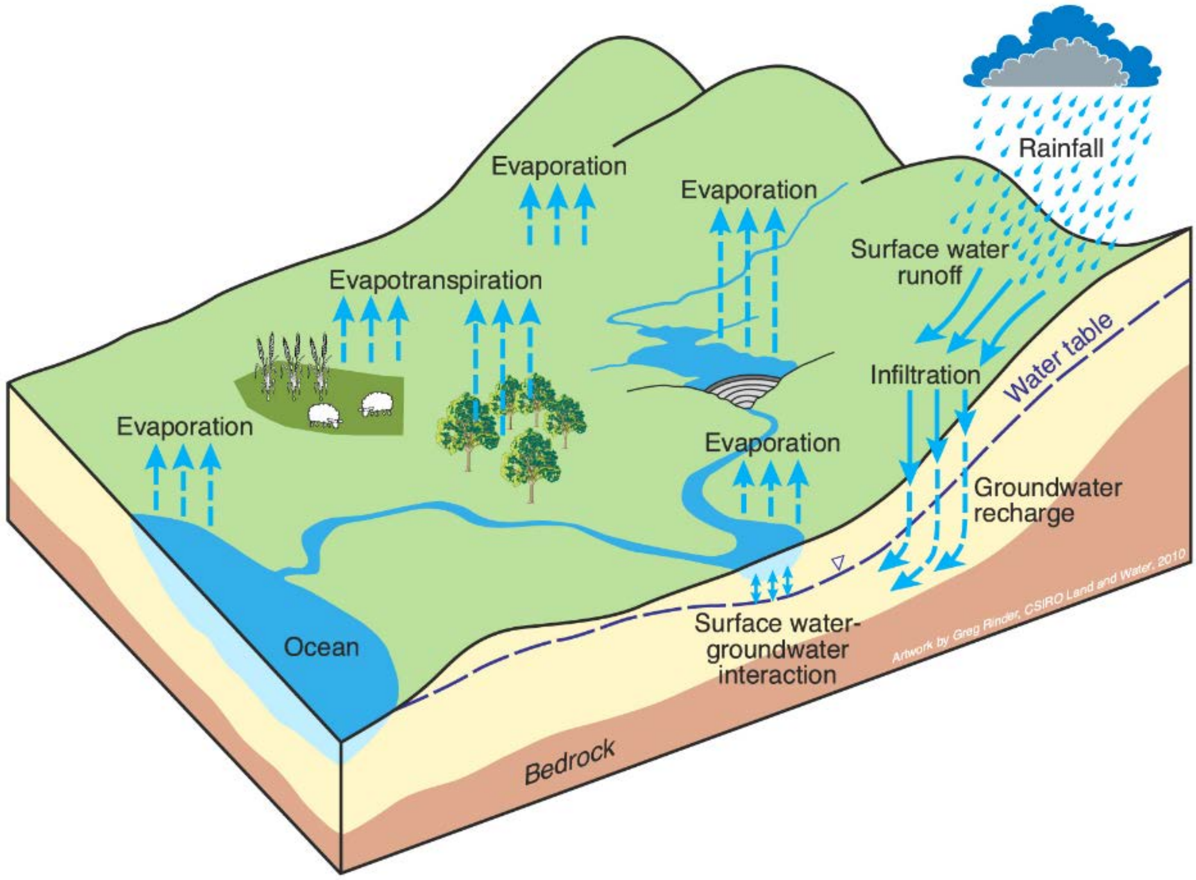


Figure 2. Simplified Conceptual Pre-Urban Development Water Balance Factors (adopted from ewater.org.au)

Understanding the conceptual water balance assists prediction of the impacts of urban development and the design of suitable water management measures. Urban development alters the pre-development water balance, potentially impacting water resources, infrastructure, amenity and the environment. Hydrological changes occur when a catchment is developed, and surface (overland), unsaturated sub-subsurface and groundwater flows may be altered. Without specific management controls, urban development in the Swan Coastal Plain may result in increases in groundwater levels due to higher post-development net recharge, through the reduction of transpiration from the loss of vegetation, and/or use of artificial rainfall/runoff infiltration systems (rain gardens, soakwells, trenches and the like), and/or the use of imported water for site irrigation (see Figure 3 below). High groundwater may also limit volumes of water that can otherwise be recharged.

Previous work by the CRCWSC and others (Barron et al, 2013; Baskar, 2016; Ocampo et al, 2017; Locatelli et al, 2017; Ocampo, 2018; CRCWSC, 2019) has increased our understanding of these processes, though several knowledge gaps remain as outlined in Appendix D which provides a summary of existing literature.

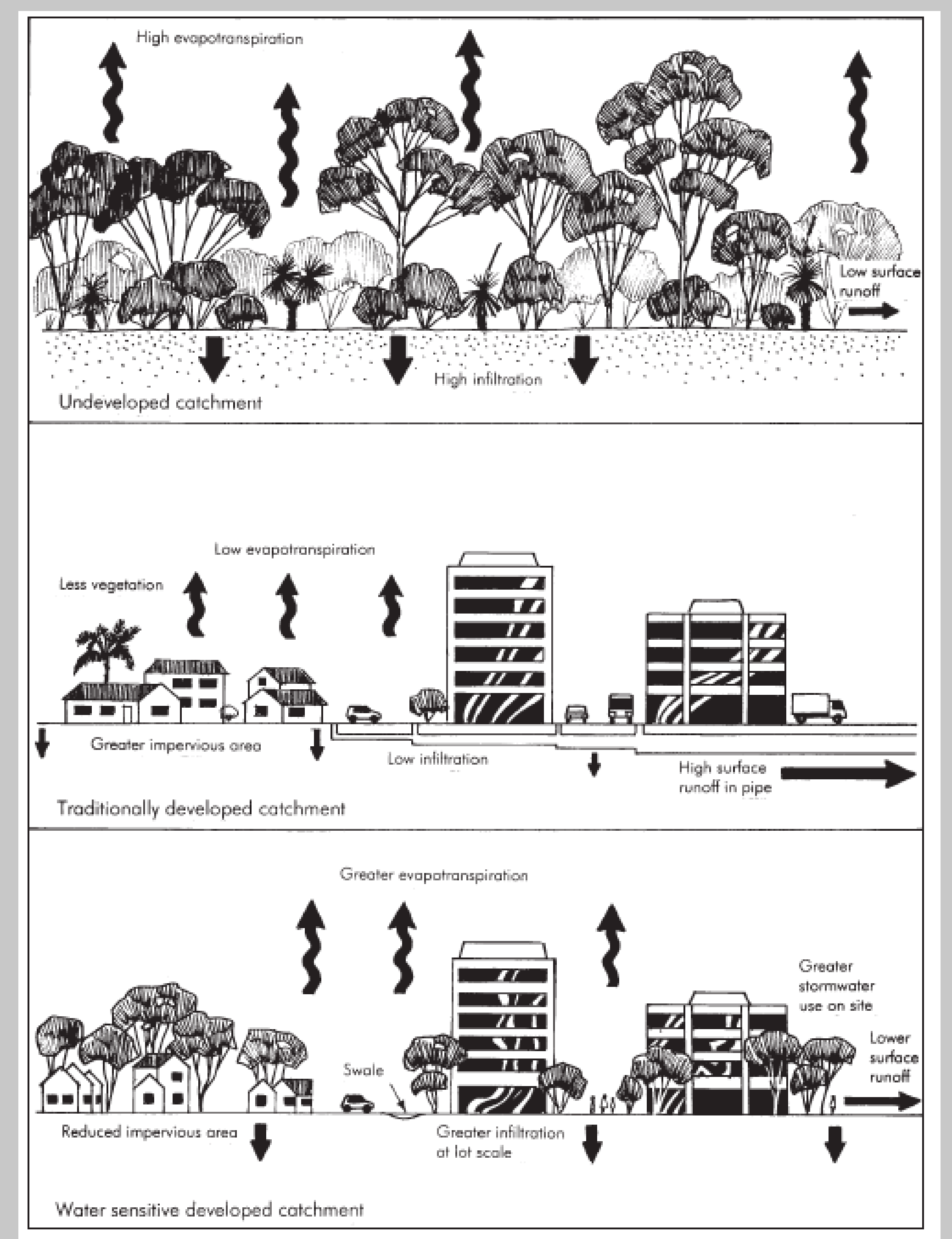


Figure 3. Simplified Conceptual Post-Urban Development Water Balance Factors (adopted from Stormwater Management Manual for Western Australia, Department of Water, Government of Western Australia, 2007)

2.4. Current development responses to high groundwater and their implications

In the Swan Coastal Plain, imported sand fill is typically used in areas of high groundwater to provide separation between urban development infrastructure and landforms and the groundwater table. There may also be sand fill requirements associated with specific infrastructure, such as wastewater management systems and road and rail alignments, and/or to create a "Class-A" site that minimises the required thickness of the concrete slab required for most housing construction methods. (Demand for double-brick houses substantially drives the residential development market.)

The use of fill in groundwater constrained sites on the Swan Coastal Plain is controlled by both "upstream" and "downstream" needs to elevate development above the natural land surface.

Upstream requirements relate primarily to achieving prescribed separation distances between the phreatic surface of the groundwater and urban infrastructure, including road bases, foundation slabs, and vegetated surfaces (turf, back yards, public open space). To achieve such conditions in high groundwater sites, developers rely on either the importation of fill to achieve a specified level of clearance above the water table, or the use of subsoil drains to lower the water table, or both.

These strategies can manage groundwater effectively. However, they have disadvantages that can be quite significant, and must be weighed against the potential gains. For example, an increasingly risk averse approach to management of groundwater risks can lead to increasing use of fill. The cost of fill is high (often at $30 per cubic metre or more with some presenters mentioning that fill can contribute more than 30% to lot development costs). This means that, if more fill is used than is really needed to provide an adequate buffer to groundwater, it can result in:

- Unnecessary additional costs to developers and thus homebuyers, decreasing the affordability of new housing;
- Unnecessary clearing/mortality of vegetation at fill sources;
- Carbon emission and transportation impacts due to importation of fill (trucking etc);
- Large changes in the elevation and relief of the built environment, potentially leading to:
    - Large grade separation between neighbouring developments, which can be unsightly and cause privacy issues;
    - Large grade separation between developments and neighbouring natural land surfaces, with increased erosion and other risks;
    - Loss of floodplain storage, contributing to elevated regional/catchment flood risks in some areas;
    - Changes in the direction and rate of groundwater flow, with potential offsite impacts, including to neighbouring groundwater-dependent ecosystems and watercourses;
    - Difficulties in retaining natural vegetation within land development sites (due to grade separations).

Conversely, where fill levels are not sufficient to manage groundwater (due to cost cutting, poor design, etc), there can be significant difficulties associated with groundwater expression. These costs are typically incurred by private landholders or Local Governments, and include:

- Damage to public infrastructure (e.g. anecdotally ~ $1 million for road replacement in one example shown to the Expert Panel);
- Damage to private property;
- Exposure to increased regional, catchment and local flood hazards;
- Loss of amenity (soggy backyards, flooded public open spaces, mosquito breeding etc);
- Exposure of Local Governments to claims for liability associated with these risks.

These examples of “upstream” controls illustrate that difficulties in groundwater management in these sites are highly visible, leading to resident complaints and requiring remedial action.

Conversely, “downstream” requirements of groundwater management are related to the disposal or use of drained water. In many sites across the Swan Coastal Plain, groundwater contains elevated nitrogen and phosphorus concentrations, meaning that this drainage water must be treated prior to discharge offsite. This treatment requirement can itself be an important driver of the use of fill to elevate the surface of the urban environment. Treatment options such as bioretention basins or vegetated swales require specified vertical separation distances from both the outlet (to a drain or waterway) and from the site drainage network (due to required grades on the drains and pipes). In practice these requirements - which govern the hydrological function of the treatment and discharge systems - often impose significant demands for fill.

As illustrated in Figure 3 below, standard treatment options can require 1-1.5m of fill over the land surface to achieve their hydrological functionality.

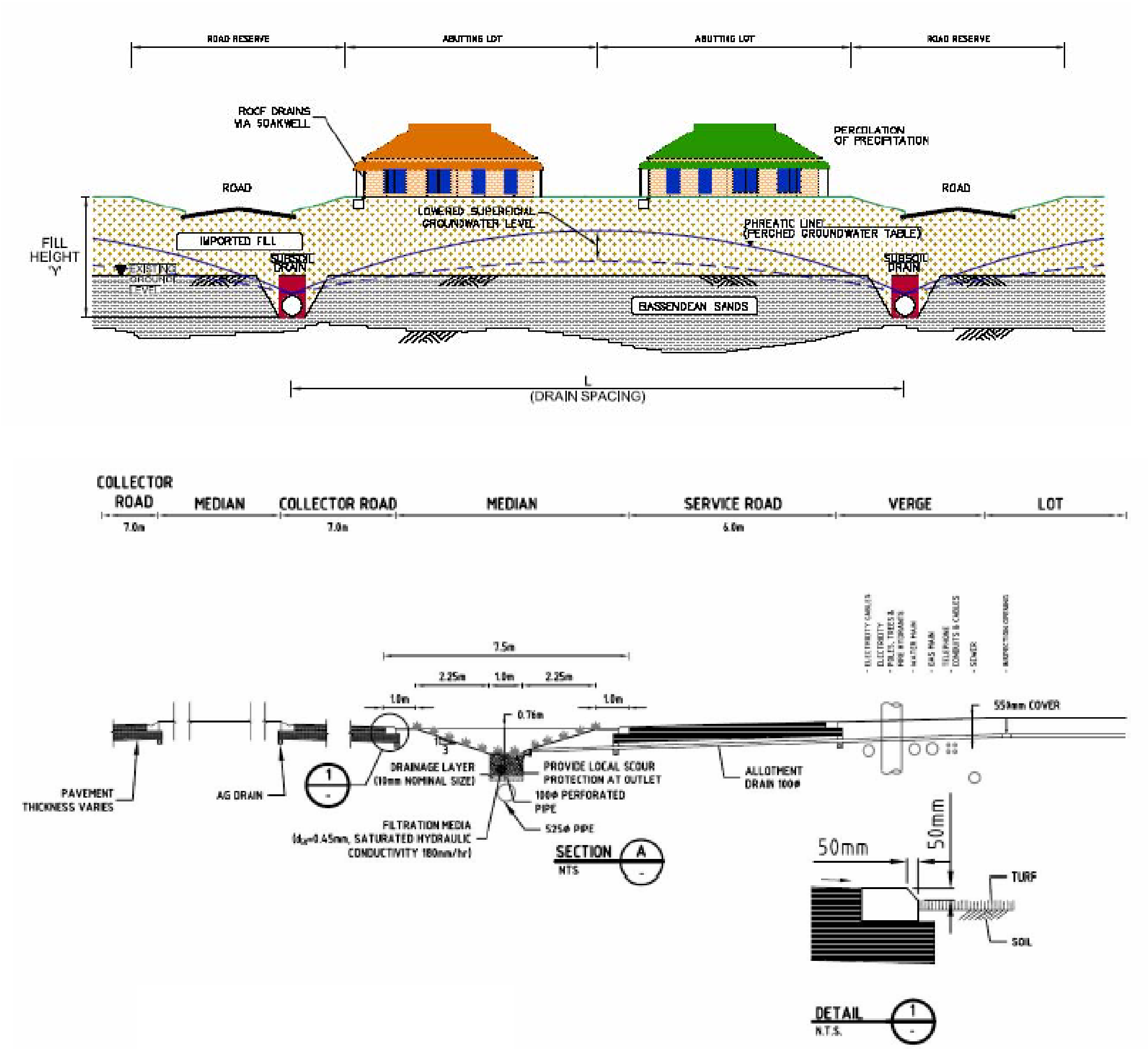


Figure 4. Typical layout of drainage water treatment systems and impacts on fill requirements (adopted from Peel Harvey Coastal Catchment Water Sensitive Urban Design Technical Guidelines, Peel Development Commission, October, 2006)

Thus, although downstream demands for fill are often less visible to residents, they represent the opportunity to address a large driver of the demand for fill. This has two consequences.

The first is that industry is aware of this large demand for fill. In a context where fill is expensive and is not itself environmentally benign, there is a need for an evidence basis to maintain industry "buy-in" regarding current "end-of-pipe" treatment practices. Recent findings that "end-of-pipe" treatment via bioretention basins and rain-gardens in the Swan Coastal Plain achieved excellent phosphorus removal but inconsistent nitrogen removal add to the ambiguity around the cost-benefit of "end-of-pipe" water sensitive urban design - WSUD (Ocampo et al 2017). Inconsistent performance may be due to these systems not being designed, built and maintained to best practice, and/or the systems intercepting groundwater when not designed to manage groundwater.

The second is that opportunities to innovate around the treatment or on-site reuse of drained subsurface water also represent opportunities for fill reduction. Interestingly, unlike several other parts of the world (see Appendix E for examples of international approaches to manage high groundwater in urban areas), very little use is made of groundwater pumping on the Swan Coastal

Plain to control groundwater levels in urban development areas. The implications of actively managing groundwater via pumping include the interactions of such pumping with the demands for groundwater abstractions and the ecological health of groundwater dependent ecosystems on the Swan Coastal Plain, and suggest that this option requires careful analysis if it were to be implemented. Other options, such as in-pipe treatment methods, retention of water onsite, reclamation of water for alternative uses e.g. via managed aquifer recharge - MAR, distributing a range of smaller treatment types throughout subdivisions (Ocampo et al, 2017)) have considerable potential to reduce fill requirements. Participants in this project informed the Expert Panel that some of these practices are already in place across the Swan Coastal Plain (in some cases having been required precisely because "end-of-pipe" treatment was ineffective). While adopting these options in a remedial sense can be costly for Local Government, their cost-effectiveness if designed upfront bears examination.

In summary, the costs associated with both "over"- or "under"-design of groundwater management and treatment strategies is suggestive of opportunities to find more optimal or "win-win" approaches to groundwater management that benefits private, public, corporate and environmental interests. For example, one participant in this project estimated an approximate 10:1 payoff for developers by improving site characterisation and modelling upfront (advising of corresponding costs in the order of tens of thousands of dollars) and consequently reducing fill costs (with in the order of hundreds of thousands of dollars worth of fill saved).

Overall, improved practice surrounding management of development on high groundwater on the Swan Coastal Plain represents an opportunity for Western Australia. It may also provide an opportunity to showcase and innovate approaches that could lead to national/global uptake.

3. Terminology

Urban development and hydrological dynamics in regions with high groundwater interface with a broad range of scientific and engineering disciplines, each of which uses different terminology and makes different assumptions. The Expert Panel experienced several situations where the same term was used for quite different purposes by different participants. The most evident example of this was the term "infiltration" which was used variously to mean:

- The process by which water enters the soil;
- The maximum rate at which water could enter the soil (i.e. infiltration capacity);
- The rate at which water enters the soil (i.e. infiltration rate);
- The rate at which water replenishes groundwater (i.e. net recharge);
- A volume of water that can be held within the soil (i.e. a cumulative infiltration volume).

While the term "infiltration" is appropriate to all of these contexts, its quantitative interpretation is quite different amongst them. Participants in this project also used the term "recharge" quite differently. It is the Expert Panel's opinion that casual use of terminology represents a potential source of misinterpretation, confusion and error, and we recommend that practitioners attempt to be explicit and to adopt a consistent glossary of terms to avoid such problems (see Appendix G for one such Glossary used in this Report).

Additionally, persons working on the problem of land development in the Swan Coastal Plain appear to have developed several colloquial terms of practice, not all of which were familiar to all members of the Expert Panel. While we, in practice, enjoyed the colour that terms like "shandy-ing" bring to the otherwise dry problem of groundwater and surface water mixing in a given environment; the Expert Panel members were concerned that such terms might also cause confusion, particularly in the context of an international and diverse workplace. We recommend that practitioners reconsider the use of colloquial terms that describe technical outcomes, and, if not avoiding these completely, ensure that such language is adequately explained and does not become a barrier to good communication.

4. Guidance

The contents of this section are based primarily on the matters raised during the discussions that the Expert Panel had with participants in this project and during meetings with and feedback on an earlier Draft Report from multi-stakeholder groups. The topics and comments are also informed to various extents by the Expert Panel's knowledge of available literature and the experience and observations of the Expert Panel's members.

The contents are therefore not necessarily fully comprehensive nor do they necessarily cover all of the most significant issues that may be faced. For example, while high groundwater conditions are often associated with acid sulfate soil risks on the Swan Coastal Plain, these matters were not routinely raised with the Expert Panel. We are also aware that there is already a considerable body of guidance material available for identifying and managing acid sulfate soil risks (Department of Environment Regulation 2015 – 1 and 2), so, we have not included guidance on the management of acid sulfate soils in this Final Report.

In a similar vein, we have not provided further commentary in this Final Report on a number of important considerations for surface water or flood modelling, such as the selection of so-called "runoff coefficients", as we note, for example, that the multi-stakeholder Land Development in Groundwater Constrained Environments Steering Group is currently quite actively considering such matters and we do not wish to cut across those discussions at this time.

With these factors in mind, the Expert Panel offers the following observations, findings and guidance for the purpose and spirit of assisting practitioners and regulators in their consideration of best practices and dealing with technical uncertainties. Not all of the following contents are purely technical in nature (and may arguably be outside the Expert Panel's terms of reference), but they may influence technical considerations and implementation of otherwise sensible technical solutions that would be supported by the Expert Panel.

4.1. Cumulative impacts of development

Urban development in areas of high groundwater can have important cumulative environmental and natural hazard impacts. Specifically, urban development over high groundwater may impact:

(a) Regional and catchment flood behaviour

Areas of high groundwater often coincide with low-lying, flat environments, including several major floodplain areas along the Swan Coastal Plain. Therefore, development in these areas can impact regional and catchment flood risks.

The processes by which urban development interacts with regional and catchment flood behaviour varies depending on the severity of the flood.

For larger events (greater than 10% AEP), loss of available storage (or connectivity to available storage) on the floodplain associated with land levelling and filling is a major process of concern, potentially exacerbating the severity and extent of regional and catchment flooding. This warrants careful consideration. Loss of connectivity can be threshold-like in nature: for example, the final development in a floodplain area may sever connectivity between a channel and available storage in the floodplain. This nonlinearity has the potential to cause large inequities in risk, cost and mitigation requirements between otherwise comparable developments in the same floodplain area.

Changes in land surface characteristics and stormwater management, and the interaction of these processes with groundwater in urban areas may also exacerbate flood inundation risks, but are most important for "nuisance" flooding (i.e. less than 50% AEP). Nuisance flooding, although rarely responsible for loss of life, can nonetheless be extremely costly (Moftakhari et al., 2017).

The processes responsible for altering flood risk for intermediate events (up to the 10% AEP) in urbanised areas over high groundwater remain poorly explained and we recommend further research and investigative effort and guidance on these matters.

(b) Changes in the local direction, volume and timing of groundwater flow, and impacts on sensitive environments

Elevating the land surface through the use of fill has the potential to alter the phreatic surface throughout the developed site relative to a pre-development condition; and to create new gradients in the water table surface. These gradients can result in changes to the local direction of groundwater flow, which are compounded by changes in the timing and availability of groundwater (e.g. a reduction in seasonal variation due to irrigation of public open space and gardens).

In addition, there may not be a clear understanding about how more localised seasonal perched water table systems interact with broader scale surficial unconfined aquifers. Ecosystems may depend on perched aquifers, which can provide a source of water as a surface or subsurface expression of groundwater. Recognition that a groundwater body is potentially perched is necessary for appropriate groundwater management as groundwater flow pathways in a perched system may differ significantly from those in the underlying flow systems. The conceptualisation of a perched aquifer setting requires careful consideration (and investigation) of the potential hydraulic connection between a perched aquifer and an underlying aquifer (Richardson et al, 2011).

There are also locations around the greater Perth metropolitan area where potentially sensitive environments are completely surrounded by urban developments that use fill (e.g. Figure 4(A)). The implications of the cumulative impacts of such developments, either in terms of alterations to hydrology or how these alterations may impact ecosystems, represent, in our view, a potentially significant environmental impact of urban development in high groundwater sites and one which would be most appropriately assessed at regional, district and catchment scales to allow the evaluation of cumulative impacts.

(A)  (B) 

Figure 5: (A) An area in Perth surrounded by multiple urban developments, many of which use fill to elevate the land surface. The implications of this local elevation of the land surface on the local-regional groundwater dynamics, and of any such hydrological changes on the ecology of the nature reserve, are unclear. (B) A lake in the greater Perth metropolitan region showing the tell-tale green tint of an algal bloom. Eutrophication in the lake is primarily driven by groundwater inflows, and became problematic approximately 15-20 years following urbanisation of the surrounding area.

(c) Regional, district and catchment nutrient loads to sensitive environments

Urban development can result in the mobilisation of groundwater with high nutrient concentrations, through subsoil drainage, or through changes in the local elevation and gradient of the phreatic surface. Although regulations can and do address the management of nutrient levels within discharge from the subsoil drainage system, the management of nutrient export to sensitive environments via groundwater flow paths (and the management of its alteration by land development) was not widely discussed with the Expert Panel. However, anecdotally, there are several examples of sensitive environments that have been adversely impacted by nutrients in groundwater drainage following urban development. For example,

Figure 4(B) shows evidence of a blue-green algal bloom event in a lake in the greater Perth metropolitan area in 2017. Current management of the lake, which has successfully reduced blue green algae impacts, is to actively pump groundwater upstream of the lake, reducing groundwater inputs to the lake, which are the source of the majority of the nutrients fuelling the algal bloom. Reportedly, these nutrient issues began approximately 15-20 years after urbanisation, but it is unclear what drove that delay.

Urbanisation therefore has the potential to exacerbate flood hazards, and to change local hydrology and local water quality with broadly unknown impacts on sensitive neighbouring environments. Most of these impacts arise as the cumulative outcome of land development at regional and district scales. Current planning practices, in which detailed water management plans are typically developed and evaluated for individual land packages (i.e. at the local structure plan approval phase), make it difficult to address these cumulative impacts. Additionally, given the diversity of authorities with responsibility for different water bodies, ecosystems and development, the potential for these cumulative environmental impacts suggests that there would be benefit from consolidating communication and the exchange of advice between Local Governments, relevant State Government agencies and other authorities with statutory oversight of cumulative impacts.

Further, there exists an opportunity for the relevant State Government agencies in partnership with industry and Local Governments to develop regional, district and catchment modelling frameworks and undertake increased modelling at regional, district and catchment scales. This practice is undertaken in other parts of Australia and warrants further consideration on its applicability to Western Australia. In this way, there will be a better opportunity to better understand where subsurface drainage will go, how it will impact GDEs, how water quality will be affected, how its abstraction will impact regional and local groundwater levels, who will bear the costs for offsite management and remediation of poor quality water and the like. This can also be a further area of research, recognising that multidisciplinary research, that more broadly considers these impacts, will help decision makers to identify suitable urban development.

4.2. Site-based risk assessment

Despite the potential for cumulative impacts of development as noted above, the Expert Panel was informed that, for most locations, the pertinent scale on which technical groundwater assessments and modelling are undertaken is for an individual development parcel.

The risks associated with the presence of high groundwater (to either the development itself or to sensitive neighbouring environments) are not uniform across all sites, and this lack of uniformity means that the appropriate level of site investigation, modelling and design/management should also be tailored to the level of risk.

Therefore, we recommend that the first assessment that developers and consultants should undertake is a risk assessment to classify the land parcel into one of three broad categories of risk. Further, adopting a consistent agreement about this classification and its consequences with planners and regulators across municipalities would streamline expectations for developers and become an initial evaluation approach for Local Governments.

The three risk categories below are presented in initial qualitative rather than quantitative terms, and then summarized in a risk matrix that attempts to identify indicators of risk. In general, the risk attached to a site should be the highest risk level flagged by the presence of any individual indicator suggested below and in Table 1.

The Expert Panel recognises that the details for these risk categories may be improved over time as further information becomes available and local understanding grows. We recommend that the guidance be updated from time to time accordingly.

The Expert Panel also recognises that risks associated with urban development in high groundwater areas often fall within a spectrum, rather that always fitting neatly into a low, medium or high category. In addition, there is likely to be a "step-change" in the level of monitoring, investigations, modelling and assessments required (and corresponding time and financial resources) as one moves from low to medium risk and medium to high risk sites. Consequently, the choice of approach needs to be considered carefully, justified transparently and preferably agreed early between the proponent and the regulator. The provision of guidance around risk levels is intended to be the basis for such discussions, not a proscriptive requirement.

Low risk:

Low risk sites are those where:

- "High" groundwater is nonetheless deep enough (e.g. greater than 2m below the surface in sandy soils) to accommodate subsurface infrastructure between the water table and the land surface in all likely events;
- There is unlikely to be a large change in net recharge (i.e. recharge - evaporation from the water table) between pre- and post-development conditions;
- Soils are homogeneous, permeable and well characterised;
- Any subsoil drainage water would be retained onsite or consumptively used offsite;
- Neighbouring land parcels do not contain sensitive environments (GDEs, streams, or other high value natural environments)
- Pre-development land use is unlikely to have created legacy nutrients or other groundwater contamination.

In these sites, although the water table may be within 4m of the land surface, it is nonetheless unlikely to interact with urban infrastructure, to be greatly changed in its level by urbanisation, or to present a water quality threat. Moreover, these sites are well understood in terms of their geotechnical and soil behaviour. They might therefore be considered to be relatively *low risk*.

Moderate risk:

Moderate risk sites are those where:

- "High" groundwater lies approximately 2m below the land surface, or will be controlled at around that level via the use of subsurface drainage;
- There is potential for some moderate change in net recharge (i.e. recharge - evaporation from the water table) between pre- and post-development conditions;
- Soils exhibit some heterogeneity and are more challenging to characterise;
- Drainage water requires offsite disposal, but the site is unlikely to have significant legacy nutrients.

In these sites, engineering techniques, specifically subsoil drains, are likely to be employed to control the phreatic surface. This level of control may successfully manage risks associated with high groundwater, provided the drains are appropriately designed. In sites where there is confidence in soil properties and post-development changes to net recharge, this design can focus on the question of drain sizing, grade and spacing, without requiring complex modelling. Such sites might therefore be considered to be relatively *moderate risk*. Note that even in sites using subsoil drainage for groundwater control, the presence of legacy nutrients, nearby sensitive environments, or the potential for large changes in net recharge associated with land cover change could elevate risk.

High risk:

High risk sites are those where any of the following may apply, individually or collectively:

- The pre-development water table approaches or intersects the land surface;
- Large changes in net recharge (i.e. recharge - evaporation from the water table) are expected to occur between pre- and post-development conditions;
- Regional groundwater conditions tend to drive water into the site (e.g. sites located within a regional groundwater col, i.e. at the convergence of flow paths);
- Soils are heterogenous, containing significant clay or limestone, and/or are poorly characterised;
- Neighbouring land parcels contain sensitive environments (GDEs, streams, or other high value natural environments);
- Pre-development land use is likely to have created legacy nutrients or resulted in other forms of groundwater contamination;
- The site is the "last" in a series of regional or district scale development projects, such that it could generate threshold changes in connectivity and flow paths (surface or subsurface) in a catchment or sub-catchment.

In these sites, detailed investigations, assessments, engineering design and three dimensional groundwater modelling are likely to be needed (or very strong justifications provided as to why they would not be needed) to understand and manage the impacts of urban development on groundwater flow, water quality and, in some cases, regional or district scale land use change impacts (e.g. regional and catchment flooding). These sites are likely to be complex and require a higher investment in characterisation than lower risk sites. These sites may exhibit greater uncertainty regarding the direction and magnitude of future changes in recharge, and thus in both the level of the phreatic surface and in the volumes of drainage water produced. They might thus be considered to be relatively *high risk* sites.

Table 1: Risk Matrix Relating Site Indicators to Risk Classifications (Note that the criteria are notmutually exclusive.)

	Low Risk	**Moderate Risk**	**High Risk**
Pre-development groundwater level (depth)	>> 2m	~ 2m or >2m (with subsurface drainage controls installed)	< 2m or groundwater col (where mounds intersect)
Pre-development groundwater abstraction	Cleared, pastured land (no groundwater abstraction)	Some tree cover (likely some groundwater abstraction)	Dense tree cover Previous irrigation allocation (likely high gw abstraction)
Soil type	Sand only	Sand with clay lensing	Significant clay areas, or complex heterogeneous soils
Receiving environments	Waters retained onsite or used consumptively	Waters discharged offsite into e.g. surface drains	Sensitive receiving environments
Other environmental constraints	Not located near floodplains, GDEs or other sensitive environments. Isolated from other development		Proximity to GDEs Location in floodplain "Last" development (cumulative impact)
Pre-development land use / water quality	Low legacy nutrients (e.g. native bush sites)		High legacy nutrient burden (e.g. agricultural sites, wetland sites) Other contamination (e.g. brownfield sites)
Minimum modelling tools required	Controlled Groundwater Level with steady state or dynamic I-D model	Two-dimensional gw drainage model (or 1-D assessments with cautions)	Three-dimensional groundwater model (as the default without very strong justifications otherwise)

4.2.1. Guidance regarding CGL assessments

The Expert Panel is aware that guidance has been provided previously about water resource considerations when controlling groundwater levels in urban developments in Western Australia (Department of Water, 2013) and about specifying separation distances for groundwater controlled urban development (IPWEA, 2016). We broadly support these approaches and we were informed that both the development industry and regulators support them also. (The controlled groundwater level (CGL) has been defined as the invert level of groundwater controlling infrastructure.) It was however reported to the Expert Panel that additional technical work is required so the existing guidance can include increased advice regarding determination of ecological water requirements, particularly for sensitive environments. Further information about additional technical work that could be expected to further inform future guidance is provided in section 5 of this Report.

Interestingly, a number of participants in this project outlined to the Expert Panel how they use the Average Annual Maximum Groundwater Level (AAMGL) which reflects the long-term peak groundwater behaviour at a site under pre-development land conditions. It may be suitable for characterizing potential groundwater dynamics in low risk sites, but is not well suited to use in medium or higher risk sites because:

- It is not risk based (so the probability of an exceedance event is not characterised by this method); and
- It does not account for prospective changes in net recharge following urbanisation.

Consistent with Department of Water, 2013 and IPWEA, 2016, industry best practice for the determination of the CGL at a given site requires:

- Two years of onsite monitoring;
- Identifying the nearest appropriate long-term monitoring well/s;

- Bias-correcting the monitoring well data (e.g. by applying a simple additive correction factor) to match the observed onsite monitoring data over this two-year period;
- Use the bias corrected groundwater monitoring data to identify the groundwater level behaviour over the past 30 years;
- Use this this information to determine the level/s against which clearances are developed.

We have supported the use of a 30 year period to (i) avoid problems with small sample sizes (likely to arise for shorter records), and (ii) to reduce the difficulties associated with non-stationary climate in Western Australia, which will be more pronounced for longer averaging periods. Future climate projections may also be considered with cautions. The aim of the analysis of historical groundwater levels should be to obtain an adequate understanding of the groundwater behaviour, recognising the quality of the available data, trends observed or expected, risks to be managed and outcomes to be achieved.

In applying this method, it is important that monitoring data are used directly, and that regional groundwater maps such as the Perth Groundwater Atlas should *not* be used to compute the CGL. This methodology should also involve careful consideration of the selected bores used (e.g. to ascertain whether they are relevant to the development site in terms of geology, groundwater connectivity and proximity), and scrutiny of the monitoring well data behaviour relative to onsite monitoring. Very large differences in groundwater levels, very large differences in seasonal or event-based responses, or differences in the sign of any trends over that two-year period may indicate very different processes occurring between the development and the long-term monitoring bore locations. These features are indicative that the selected bore is a poor proxy for the development site.

Limited periods of record, sparse bore networks, or changes in climate, geology, and hydrologic connectivity of the groundwater between bores and development sites can all make the recommendation to use 30 years of groundwater monitoring data as a proxy unachievable or inappropriate. In these circumstances, using a shorter period for analysis may be reasonable, or alternative proxies for long-term groundwater fluctuations, such as rainfall records, could be used to drive bias correction instead. Further research could focus on developing worked examples and standard methodologies for these options.

Further, with the extent of urban development related groundwater monitoring that has been and will be undertaken, it would seem highly desirable that a groundwater information repositorybe built into which pre- and post-development monitoring data, collected to some agreed protocols and standards, could be deposited for use by the development industry and by all agencies involved in regulating and facilitating development. This would address the lack of use of these data by putting them in a georeferenced, searchable system, and would certainly start to increase the density of "ever monitored" locations across the Swan Coastal Plain.

4.2.2. Guidance regarding one-dimensional groundwater model assessments

One-dimensional (1-D) assessments have the aim of estimating the height of the groundwater mound created by recharge within a landscape in which groundwater controls (e.g. subsoil drainage) operate.

The most widely adopted method for these assessments is to use a steady state solution for flow in an unconfined aquifer between two drains - typically Hooghoudt's equation. However, the use of steady state, one dimensional equations has several limitations:

- The optimal averaging process by which to assess appropriate recharge values for sizing fill levels is unclear, supporting data and local observations may be lacking, and the steady state solution is especially sensitive to the choice of recharge values and changes in groundwater levels;
- The use of steady state techniques precludes developing a risk-based metric (so the probability of specific exceedance events cannot be characterised by this method);

- “Typical” solutions to Hooghoudt’s equation consider spatially uniform recharge, which is unlikely to occur in urbanised sites.

These issues were taken up in the IPWEA, 2016 guidelines, which recommend an approach to the use of the Hooghoudt equation, in which the 72-hour, 50% AEP rainfall is recommended for design purposes if the Hooghoudt equation is used. While this is appropriate from the perspective of reducing the risk of under-sizing fill, this approach precludes optimization of fill use.

Additionally, the use of one-dimensional models involves some challenges:

- <u>Site Characterisation</u>: particularly due to heterogeneity of site soils. In particular, care should be taken to delineate areas of clay lensing or limestone, and models run separately for different soil types within a site.
- <u>Model Parameterization</u>: Two major sources of model parameter uncertainty are relevant to the one-dimensional models: K_{sat} and its variability, and net recharge under pre- and post-construction environments, considering that rainfall events may present large temporal variability, affecting infiltration rates and allowing recovery of infiltration capacity over time.

  K_{sat} estimates should consider a realistic range of values for sensitivity analysis. The range in K_{sat} for fill sand quoted to the Expert Panel was 1 m/day – 10 m/day, with a typical design assumption of 5 m/day, and it would be sensible to understand the sensitivity of proposed designs to this range of variability. Any current practice that involves a sensitivity analysis of only +/- 10% is insufficient to capture this potential range of variability. Because fill regularly fails to exhibit the design K_{sat} value, failure to adequately characterise post-construction fill and/or test design robustness to the feasible range of fill conductivities, poses a risk. It is also important to note that, in site characterisation, K_{sat} should be measured at the relevant depth for the model and not just at the land surface.

  When considering net recharge behaviour, it is worth noting that, in terms of spatial averages, the total volume of infiltrated water is likely to be similar pre- and post- development (particularly under sites that rely on the use of soakwells to infiltrate impervious surface runoff; while sites where these areas are directly connected to the stormwater system could reduce infiltration volumes more substantially). However, abstraction, transpiration from the unsaturated and saturated zones, and evaporation from water tables are likely to be lower following urbanisation, and recharge is likely to be more concentrated spatially in urbanised sites. These issues should be addressed separately. To assess net recharge under vegetated conditions, an unsaturated zone water balance model can be used. The common current industry practice of estimating net recharge and/or evapotranspiration as a fraction of precipitation is non-physical, and particularly inappropriate if non-stationary climate conditions are to be considered. Characterisation of gross recharge beneath different components of the urban landscape remains a major uncertainty that requires further research (Ocampo, 2018).

- <u>Conceptualisation</u>: Frequently, the Hooghoudt equation is applied along a transect perpendicular to the orientation of two parallel drains. This transect is not appropriate if the drains slope downhill, because the direction of the steepest slope of the water table will then also be slanted downhill. This will effectively extend the distance over which groundwater flows. Thus, the transect distance may need to be increased. Alternatively, the site could be engineered to minimize the groundwater flow path distances between drains (e.g. by grading the subsoil clay).

  Additionally, spatial heterogeneity in net recharge across different elements of the urban landscape (e.g. soakwells versus roads versus paving versus houses) may have a significant influence on the overall shape of the groundwater mound, as can the efficiency of the drains in removing water from the soil locally.

We note that software is available to address - at least partially - difficulties associated with steady state recharge assumptions and difficulties associated with the heterogeneity of recharge, by using the Hooghoudt equation in a pseudo-steady fashion and solving it piecewise for locations of different recharge.

This approach is promising, although subject to the remaining uncertainties regarding flow path length, appropriate estimates for gross recharge underneath different forms of urban landscape, and the importance of transient conditions for creating groundwater mounding. It may be possible to use AEP methods where such pseudo-steady models are used, although the correspondence between AEPs estimated from pseudo-steady solutions and AEPs estimated for fully transient models under otherwise identical conditions should be explored before doing so.

Therefore, we suggest that best practice for use of 1-D groundwater models involves:

- Detailed characterisation of the post-development land surface or sensitivity analyses for K_{sat} that explore the full feasible range of values for fill;
- Running models under different climate scenarios to estimate pre-development net recharge rates;
- Adopting the assumption that infiltration volumes remain unchanged but evapotranspiration is greatly reduced (potentially to nothing) to estimate post-development, spatially averaged net recharge values;
- Use of pseudo-steady, spatially variable recharge tools to solve the Hooghoudt equation, including estimates of AEP.

However, future research is required to provide confidence in this approach and potentially to determine suitable correction factors, specifically:

- Developing a simple methodology to correct the drain spacing to account for additional flow path lengths for graded subsoil drains;
- Measurement and characterisation of gross recharge rates beneath different components of urban infrastructure;
- Characterisation of AEP error associated with the use of pseudo-steady rather than fully transient models.

4.2.3. Guidance regarding 2-D / 3-D groundwater assessments

Two- and three-dimensional groundwater assessments require running a distributed groundwater model. Several packages are in widespread use by consultants and broadly represent the use of best practice tools. These packages are generally necessary for high risk sites, complex designs, and in situations where developers aim to minimize the use of fill.

There are several advantages to adopting a two- or three- dimensional modelling methodology. The first is that these models are fully transient. This makes it feasible to use climate time-series to force the model. The results of long time-series or Monte Carlo runs can then be evaluated in terms of exceedance probabilities related to different peak levels of the phreatic surface, and thus used in an Annual Exceedance Probability (AEP) framework. We recommend that practitioners follow *Australian Rainfall and Runoff 2019* Book 3 Chapter 2 methods for estimating Events per Year or Annual Exceedance Probabilities from a time-series, but that practitioners develop such time-series using long-term (at least 30 year) model runs. The selection of an appropriate forcing time-series is problematic - the longer the time-series the greater the confidence in the resulting AEP behaviour, but long time-series cannot be obtained from historical weather data due to the non-stationarity in the climate. In this context, the use of stochastic weather generators to create time-series for Monte Carlo simulation may be appropriate. The AEP behaviour discussed here relates to the groundwater response probability and *not* the rainfall event probability. The aim is to understand the long-term groundwater level behaviour from the observations and the modelling.

The characterisation and uncertainty challenges relevant to one-dimensional models are not alleviated by the use of a more complex model, and again care must be taken in site characterisation, sensitivity analysis, and estimation of net recharge behaviour.

The use of both two- and three-dimensional models requires calibration and sense checking. Calibration should be undertaken to the bore levels and fluctuations in the pre-development model. Sense checks, for example ensuring that the model indicates groundwater at the surface during winter in areas of a wetland/lake, can provide better spatial insight across sites than purely relying on monitoring bores.

4.2.4. Inherent limits of model certainty

It should be noted that, in the context where minimisation of fill is a goal, it is unknown whether modelling can *ever* provide a sufficiently precise prediction to control risks associated with groundwater.

In general, the uncertainty in soil parameters, recharge rates, and model "correctness" are not well understood, meaning that the margins of error to be expected around model results are also poorly constrained. There is a need to more closely examine current approaches to infiltration modelling and consider the findings reported in Ocampo, 2018 (summarised in Appendix D of this Report and CRCWSC, 2019).

Options could be to invest in either better modelling and better understanding of uncertainty; or to consider design methodologies that are more robust with respect to the relevant uncertainties.

4.3. Design to minimize fill and/or waterlogging risks

The extent to which improved parameterisation, model sophistication and modelling expertise can reduce the uncertainty around performance of groundwater management systems, and thus give confidence about post-development groundwater levels – even in sites with groundwater controls installed, remains unknown. This means that, at present, and for the foreseeable future, there is a degree of risk associated with engineering design to control groundwater.

Broadly, this can be managed by three options:

(i) "conservative" (i.e. more rather than less) use of fill under all circumstances;
(ii) fill minimisation + design to mitigate against high groundwater;
(iii) accept that some things will not work out and "correct" them after problems emerge.

At present, many authorities are opting for option (i). As noted previously, however, conservative use of fill has many economic and environmental downsides.

Under situations where less conservative use of fill is sought, a range of designs could be employed to mitigate high groundwater at lot rears, which may be appropriate to consider given the limitations of modelling and design. These include:

(a) Landscape designs that accommodate periodic waterlogging in gardens. Examples could include the development of rain gardens/winter gardens (Harlow, N. and Coate, B.D., 2004) or the use of raised garden beds/lawns to provide clearance to *only* the components of the yard that need protection from wet soils. Adoption of these approaches could be supported by appropriate homeowner, new buyer and community education.

(b) Drainage designs that provide additional subsurface drainage from the rear of lots. For example, short and directly connected (to stormwater) subsoil drains could be installed in the expected location of the groundwater mound in the rear of each lot. Although this would create an element of drainage infrastructure that required management by homeowners (again supported with appropriate education), responsibility for maintenance could be similar to that for on-lot sewerage. Demonstration sites to show the feasibility of this approach would also be beneficial.

(c) Drainage designs that enhance drainage from the rear of lots, for example by grading any underlying clay towards road-side subsoil drains. This option has examples of proven success, but can only be used where there is underlying clay.

(d) Surface drainage from lots should also be considered in locations where high groundwater may impact lot rears, by grading the lot so that any surface flooding that does occur has a viable surface flow pathway to the street and the stormwater drains.

Additionally, fill depths may be reduced if pipe grades can be made shallower, reducing the fall needed across the pipe length. This could reduce the need for fill. Although there is experience in the USA with shallower pipe falls, and the ASCE recommends a minimum 1:1000 grade for stormwater pipes, a grade of 1:500 is more common in WA. Some Local Governments reported blockages in 1:1000 grade pipes.

4.4. Assessing performance

The performance of existing groundwater management designs, and of urban stormwater infrastructure in high groundwater areas, is not well understood. Broadly, there would be value in understanding:

- Whether systems function as designed (e.g. location and height of phreatic crests relative to predictions, volumes and timing of subsoil drainage water relative to predictions);
- How system function changes over time (e.g. does the efficiency of subsoil drains vary over their life, how is performance impacted by maintenance schedules, what is the functional lifespan of in-situ water treatment methods);
- Whether the presence of high groundwater alters system functionality (e.g. how does soakwell performance vary with depth to groundwater, how does WSUD performance vary with increasing contributions of groundwater to surface water runoff).

Developing this understanding is challenged by the requirements associated with post-development monitoring. Often monitoring is not initiated until the final stage of a multi-stage development (which may be rolled out over a 10-20 year period). This gap represents a lost opportunity for adaptive management when problems do arise. The required 2-year period for post-development monitoring, moreover, may not be sufficiently long to assess changes in system performance with age.

4.5. Available guidelines

There are many sources of guidance available to practitioners. Broadly, we recommend that site characterisation, modelling, design and approval attempt to be done in agreement with:

1. The IPWEA WA draft *Specification for Separation Distances for Groundwater Controlled Urban Development (2016)* and references contained within. We note that during the consultation process we spoke with several stakeholders who remain concerned that some clearances in this document (lot rears and playing fields were most commonly mentioned) may not be sufficient to reduce risks to acceptable levels. However, it is not clear if the waterlogging reported at such locations is actually due to insufficient clearance or whether there were confounding factors such as poor design, poor parameterisation (K_{sat} etc), lack of maintenance, blockages in the designed system, or unforeseen outlet controls. These specific levels and clearances should be subject to ongoing discussion.

2. *Australian Rainfall and Runoff 2019* – ARR represents a national consensus regarding best practice in numerous areas relating to urban stormwater management. It is recommended that Local Governments and State Government agencies adopt and publicise their adoption of ARR requirements as updated in 2019. Designs or analyses that use outdated methods, or that attempt to mix-and-match methods from different iterations of ARR, cannot be considered best practice.

While mentioned by only a few of the participants in this project, we also recognise and support the use of documents such as the Australian groundwater modelling guidelines (Barnett et al, 2012), the Australian GDE assessment framework (Richardson et al, 2011), the WA Local Government Guidelines for Subdivisional Development (IPWEA, 2017), and several documents produced by the Department of Water (Department of Water 2007, 2008, 2013) to support water sensitive urban design (WSUD) and the Better Urban Water Management (BUWM0 framework (WAPC, 2008).

4.6. Approaches to standardise aspects of modelling and design review

Local Governments are a key decision-maker with regards to urban water management plans, and Local Governments also frequently incur liabilities associated with failure to adequately manage groundwater/surface water in urban developments. Local Government agencies are acutely aware of these responsibilities and concerned about their capacity in terms of both skilled personnel and time/finances to fulfill them in increasingly complex development environments, including those impacted by high groundwater.

In this context, approaches that can simplify, streamline and support Local Government decision-makers would be valuable. One such approach would be to develop checklists that can be used to rapidly “sense check” modelling for individual sites.

For example, Local Government could require that consultants supply them with models of the pre-development water table level, a pre-development LIDAR surface (if available), pre-development aerial photography, and post-development land elevations and modelled water table levels. With these data, (particularly if they could be dynamically overlaid with each other) it should be possible to identify some basic questions about the coherence between models of groundwater behaviour and observations. For example, Local Government authorities could check that:

(1) Surface water features such as lakes and wetlands in the site are consistent with the predicted groundwater surface. (The difference between the land surface and the watertable height should be >0 at these locations.)
(2) The post-development surface provides sufficient clearance to the modelled groundwater levels. This could enable authorities to determine if the design is robust to any errors/uncertainties/assumptions identified in groundwater modelling.
(3) High groundwater locations (and any errors/uncertainties associated with the estimation of the phreatic surface in those locations) will not have problematic implications - for example on the functioning of Public Open Space or other aspects of liveability.

At present, a key limitation to employing such approaches may be software and access to geospatial tools, resources and skills. Developing open source and accessible graphical user interfaces (GUIs) to automate these tasks for Local Government authorities could greatly facilitate these kinds of checks.

4.7. Capacity building and advice

Not all Local Governments have appropriate capacity to assess technical, hydrology, hydrogeology, and/or engineering information, including modelling. There are two major sources of difficulty: (i) the lack of a funding model to support time investment in such assessments, and (ii) whether Local Governments can employ personnel with sufficient technical expertise to perform them. In addition to the points raised in Section 4.6, further institutional changes could potentially create such capacity.

Several participants indicated that a centralised technical review/advice hub (hosted by, for example, Regional Councils or a collection of Local Governments) could provide a way to consolidate this role with appropriate specialists. Professional representative bodies such as IPWEA, Engineers Australia, the Australian Water Association and others and local initiatives such as New WAter Ways can also play a beneficial role in this space through training, peer support, mentoring, networks and the like. For example, industry and regulator capacity could be bolstered by further education and training programs, especially for early and mid- career professionals, building on up-to-date guidance materials and those delivered by New WAter Ways, the National Centre for Groundwater Research and Training and others

4.8. Legal frameworks

There are several subject areas in Western Australia (and elsewhere) where legal frameworks surrounding the management and responsibility for drainage infrastructure are unclear. More specifically:

- Responsibility for groundwater drainage infrastructure housed within private lots is not well understood and this has implications should such an approach be otherwise technically sound. This also has implications for maintenance, in particular, and, without appropriate maintenance, adverse impacts can happen not only on lot but more broadly.
- Drainage, especially drainage of the type relevant to management of water in areas subject to high groundwater, is not subject to specific legislation, although the Local Government Act and the Common Law both address some aspects of drainage. Issues such as infrastructure on private land which needs to be maintained to achieve public good (e.g. subsoil drainage systems) falls into a legal grey area and may subvert otherwise sensible technical solutions.

While it is not within the Expert Panel's terms of reference to bring forward specific suggestions for improvements in legal frameworks relevant to urban developments and drainage in high groundwater environments in the Swan Coastal Plain, we certainly do encourage stakeholders to further explore the policy issues and options, including greater legislative clarity, to reduce or remove barriers to the implementation of otherwise sensible technical solutions.

4.9. Changing building practice and behaviour

Many participants speaking with the Expert Panel indicated frustration with the lack of innovation around building methodologies and urban and built form and how these intersect with water management. Demonstration projects would provide important certainty around innovation in this space which could encourage greater experimentation and confidence in a broader range of building and urban development strategies. Areas where demonstration projects may be particularly valuable in locations subject to high groundwater risks include:

- Projects using "novel" house construction methodologies other than concrete slab on ground and double brick exterior walls (e.g. projects using so-called "lightweight construction");
- Projects that innovate with on-lot and/or whole-of-development water detention (versus infiltration/disposal);
- Projects that implement on-lot mound drainage;
- Projects that innovate around garden or other landscape design for high groundwater in yards and public open spaces.

4.10. Changing the planning, building and construction approval processes

Under current planning and approval frameworks, the Expert Panel heard that it is challenging to achieve consistency between environmental design, civil design, and the "as built" nature of developments. As it is desirable to seek to optimise designs around groundwater management (for instance, by requiring the use of particular soakwell specifications and locations to achieve appropriate groundwater clearance), then this challenge may need to be confronted. This challenge is exacerbated by separation of responsibilities under different pieces of legislation and within many Local Government departments.

4.11. Recovery of groundwater drainage waters

The recovery of groundwater from subsoil drainage systems represents a potentially valuable water supply option. This is an exciting and important opportunity for development to be synergistic with improved water sustainability. To date, other than work by Davies et al (2018), research in this topic still remains fairly preliminary (e.g in locations where existing groundwater use entitlements are fully allocated and/or fully utilised but unmet water demands still exist or are increasing), and it is the subject of scrutiny by a number of stakeholders, including water resource management and regulatory agencies. We have been informed that the Water Corporation and the DWER in partnership with other stakeholders have been undertaking a Feasibility of a Subsoil MAR Trial, which will help address some of the issues. This project can provide some further information on recovery of groundwater drainage waters. The Expert Panel considers it too preliminary to offer guidance on how to undertake such recovery, but strongly supports ongoing investigations into realising the benefits of this potential water source, whilst also ensuring that use and reuse of groundwater from subsoil drainage systems have acceptable water quality and ecological impacts.

4.12. Performance of WSUD in high groundwater environments

The presence of high groundwater can impact the performance of numerous Water Sensitive Urban Design (WSUD) technologies, for example by altering conditions in the unsaturated zone and thus changing infiltration rates and detention times, or because groundwater discharge downstream of WSUD infrastructure can re-introduce high nutrient water following treatment (see, for example, Ocampo, 2018 and other previous work by the CRCWSC). The Expert Panel saw several cases where WSUD infrastructure had been designed and/or constructed inappropriately for the high groundwater conditions and so was not performing well. In addition, we saw cases of poor or no maintenance leading to ineffective performance of the WSUD infrastructure.

In general, WSUD design should be able to accommodate high groundwater *if* the design is undertaken with an awareness of the presence, behaviour and quality of groundwater, and is optimised to treat groundwater or to account for the implications of groundwater on the hydraulics of WSUD elements. Thus, WSUD in these environments should be designed deliberately with the hydraulic and water quality implications of groundwater dynamics incorporated into WSUD design.

4.13. Off-site impacts of fill on hydrology, hydroperiod and ecology

Many interview participants agreed that it is probable that extensive urbanisation and widespread use of fill in proximity to sensitive natural environments (particularly GDEs) will alter the hydrology and hydroperiod of these environments. However, the Expert Panel did not hear much discussion of this issue as needing management through subdivision drainage design, and no one we spoke with was aware of specific monitoring to document this issue. The Expert Panel is aware that this may reflect a gap in the range of stakeholders interviewed. However, there was some commentary that significant groundwater quality impacts, including biogeochemical impacts, on some parts of the Swan Coastal Plain have arisen as a result of urban developments and modification of groundwater levels in recent decades. Nonetheless, there appears to be a need to determine the impacts of the extensive use of fill and the resulting grade separations between natural land surfaces and urbanised land surfaces on hydrology and hydroperiod in sensitive environments.

4.14. Clarity of geo-technical investigations and options

On several occasions, the Expert Panel heard of the challenges that modellers, design engineers and assessment staff faced while interpreting and evaluating the results of geotechnical investigations, especially in highly complex and heterogeneous sites and with different methods used to measure parameters including basic ones like hydraulic conductivity. Hydraulic conductivity can be measured in the field or in the laboratory, using several standard methods. It was mentioned that at least five different methods are commonly used in the Perth region. It should be noted that the estimates (typically of saturated hydraulic conductivity) are not necessarily comparable between these methods. A standard approach needs to be adopted for consistency and added to procedural guidelines.

It is important that there is not a mismatch between the geotechnical information and what the hydrologists are trying to do with it. Close liaison between the two professions is needed as investigations and assessments are undertaken. This includes geotechnical investigations both at the development site and for any fill materials that may be imported. Participants in this project reported that they had observed significant differences in fill geotechnical and hydraulic properties, even at lot scales. This emphasised the importance of post-development/post-compaction tests.

In addition, some comments were raised with the Expert Panel about the lack of clarity in the hydraulic performance (imperviousness or lack thereof) of peat, especially in circumstances where it is not removed from the site and replaced with imported fill, with such removal and replacement being the more common practice for residential development on the Swan Coastal Plain. The Expert Panel was not made aware of any work which would provide evidence of performance under a range of circumstances and so this could be a topic for further research and investigation, recognising that there may be the potential for groundwater acidification, increased underground fire risk, as well as carbon dioxide emissions, as well as impacts on the surface and subsurface flora and fauna that such soils sustain.

4.15. Transparency and coherence in technical reports

As mentioned previously in this Report, the Expert Panel is aware that a number of documents have been prepared to provide guidance on the preparation of district and local water management strategies and urban water management plans under Western Australia's Better Urban Water Management framework (see for example the Department of Water and Environmental Regulation's website www.dwer.wa.gov.au or http://www.water.wa.gov.au/planning-for-the-future/water-and-land-use-planning/better-urban-water-management). However, in discussions with the Expert Panel, several participants indicated that further guidance is desirable and better practices are required for transparency and to justify the modelling parameters and assumptions used to support those strategies and plans. This includes demonstration of consistency and coherence in modelling across the various scales of planning and design, justification for any changes made, sensitivity testing and handling of uncertainties.

This Report only goes a small way in providing such additional guidance and further development of it over time is supported as new data, information and knowledge become available.

5. Recommendations for future research or other work

Additional research is needed in numerous areas that were shared with the Expert Panel. A number of those needs have been identified and ways of addressing them have been described in various sections earlier in this Report. In this section, we have focused on the priority technical knowledge gaps and needs for new tools associated with development practices in high groundwater environments on the Swan Coastal Plain. It is therefore not a comprehensive list of technically related research needs, nor does it cover specific improvements in commercial, legal and planning frameworks surrounding urban development, which were beyond the brief for the Expert Panel. Despite this, we certainly do encourage stakeholders to further explore the policy issues and options, including greater legislative clarity, to reduce or remove barriers to the implementation of otherwise sensible technical solutions.

The priority knowledge gaps identified here are to:

(i) improve understanding of recharge dynamics of the pre- and post-development landscape,

(ii) improve understanding of the risks associated with common modelling assumptions, and
(iii) develop tools to facilitate assessment of proposals by Local Governments.

Further longer-term work includes the establishment, monitoring and evaluation of demonstration projects as discussed in sub-section 4.9 and below to extend proof-of-concept ideas into reality and achieve practice change under WA conditions.

It is acknowledged that while the above priority knowledge gaps should be progressed, research in this area will be of limited benefit if it is not well understood how changes to the local hydrology (including water quality) will impact on the receiving environments or adjacent environmental assets. Current research underway to better identify and understand impacts of urban development on estuaries is supported, while consideration could be given to undertaking similar research with respect to terrestrial ecosystems. For example, what are the ecological water requirements and what are the tolerable changes to groundwater levels and quality such that key groundwater dependent ecosystems are protected? This underlying need is fundamental to the protection of Western Australia's environmental assets and should be a consideration in all stages of research, modelling, legislative approvals and development.

While the priority list below can sensibly be undertaken in the order as presented, it can also be progressed iteratively as resources and circumstances permit. It is the considered view of the Expert Panel that undertaking this further work will lead to better informed decision making, mitigation of unacceptable risks and better environmental, economic and liveability outcomes.

Without progress in the below areas of research and further work, and the development and following of improved guidance, we believe that impacts of high groundwater will continue to generate harm in several areas of urban development and sensitive environments within the Swan Coastal Plain; result in the use of excessive amounts of on-site sand-based fill, which add to urban development costs and impact housing affordability, and lead to nuisance flooding and damage to public and private infrastructure in at-risk locations.

5.1. Improve understanding of recharge dynamics of the pre- and post-development landscapes at a range of scales

Despite many years of groundwater level monitoring (and in many cases the available data not being analysed) and the considerable amount of detailed work that has been undertaken for regional scale groundwater assessment and modelling (Department of Water, 2009), the evaporation and transpiration dynamics of pre-development high groundwater landscapes across the range of relevant scales are poorly understood.

In addition, past work recognises that recharge is more sensitive to water level change when the water table is close to the surface. For example, Barr and Barron (2009) simulated that the average monthly ratio of infiltration to rainfall has a subtle maximum in June and then slowly decreases for the rest of the wet winter period. This is because the water table reaches the surface in the low-lying areas, either stopping the infiltration altogether or reducing the infiltration rate to the same rate as leakage to the deeper parts of the aquifer. They classified this as a 'rejected recharge', which may offer opportunities as a consumptive water source. They also simulated that the monthly ratio of recharge to rainfall has a minimum in late autumn (May) and then increases through the winter-spring period. The gradual increase in the recharge occurs because infiltration associated with the early winter rain takes time to infiltrate through the soil profile to recharge the deeper water table areas, and because the rise in the water table during winter reduces the time taken for the infiltration to reach the water table.

Of course, recharge dynamics are much more variable than even monthly changes would indicate and such changes are important to the planning and design of urban developments. This not only means that characterizing recharge in pre-development landscapes is difficult, but that it is difficult to understand likely net recharge changes post-development which are often driven less by increases in the volume of water infiltrating and percolating through the unsaturated zone following land cover change, and more driven by changes in water uptake from the unsaturated zone/capillary fringe following removal of pre-development vegetation.

In the context of the post-development landscape, recharge is likely to be highly spatially variable depending on the installation of subsurface infrastructure (e.g. soakwells, drains) and land cover features (e.g. roads versus paving). There has been very little research done to quantify these differences which can be quite influential on the spatial pattern of the phreatic surface (according to models). Measuring recharge across the range of these infrastructure types, ideally under different conditions (e.g. soakwells with large, small or no clearance to the phreatic surface; on sands or in fill above clay) is important to better understand the performance of infrastructure and site-level water table dynamics. It is recognised that such performance may well change over time, so targeted long-term drainage and related water table control infrastructure performance monitoring, assessment and evaluation are also matters for further research, as previously outlined in sub-section 4.4.

Building on the findings and recommendations of previous projects by the CRCWSC (Ocampo, 2017; Ocampo, 2018; CRCWSC, 2018), this work should be the essential ingredient of the next phase of IRP5, commencing in early 2020. The research can also be augmented over time by appropriate analyses and evaluation of pre- and post-development monitoring already (or to be) undertaken by developers and/or their consultants and by incorporating water quality and future climate impacts. There are considerable opportunities for the urban development industry, regulatory agencies and academia to work cooperatively together to improve the knowledge base and so improve best practice guidance over time. Research that would develop/assess new and innovative technologies/methods to measure aspects of the urban water balance, that are more accurate, more practical, cheaper, more reliable, and/or more suited to urban systems than currently exists, should also be considered.

5.2. Improve understanding of the risks associated with common modelling assumptions

One of the most common simplifications associated with modelling is the use of steady-state equations to describe the phreatic surface. By neglecting transient conditions, these equations may over- or under-state the risks of the water table crossing defined thresholds. Transient modelling of comparable scenarios (e.g. comparing Hydrus 2D models to SammEE) across multiple winter storm realisations and for different soil/infrastructure conditions would readily provide insight into the risks being entailed by the use of steady-state approaches, and whether they are reasonable or not.

Additionally, exploration of steady state flow paths between inclined drains with three-dimensional models could be readily used to develop guidance regarding the appropriate selection of a transect along which to apply 2D flow equations.

5.3. Develop tools to facilitate Local Government assessment of proposals

Consultation with practitioners identified several low-cost and sensible immediate checks that Local Government could make to ‘sense check’ consultant modelling. Many of these, however, require some level of GIS expertise, which is not available in all Local Governments. Developing tools that facilitate assessment through these methods (e.g. which are based on open-source software and provide a user-friendly GUI) would be a very useful step forward. If Local Government capacity and capability to provide good assessment can be bolstered, it would provide a very useful check against problems in the design phase. Industry and regulator capacity and capability could also be bolstered by further education and training programs, especially for early and mid- career professionals, building on up-to-date guidance materials and those delivered by New WAter Ways, the National Centre for Groundwater Research and Training and others.

5.4. Proceed towards the creation of demonstration projects

Many participants and the Expert Panel believe that more demonstration projects are needed to address many of the issues raised previously in this Report, for extending proof-of-concept ideas into reality and achieving practice change under WA conditions. It was suggested to the Expert Panel that there are two forces at play to effect "change to the status quo" – 1) change to/within the development industry and 2) change to consumer demand/expectations/behaviour. If this recommendation is prioritised to proceed in the next phase, it may be necessary to consider how demonstrations will change both development industry and consumer demand. Suggested topics include:-

- Alternative construction methodologies and urban and built forms appropriate to high groundwater environments;
- The performance of a variety of precinct, sub-division, and on-lot stormwater management strategies;
- The feasibility of rear-of-lot directly connected drainage of the local groundwater mound; and
- Landscaping approaches that are compatible with high groundwater in lot rears and public open spaces.

5.5. Cooperatively develop further guidance

The Expert Panel has been very impressed by the passion, enthusiasm and commitment of the practitioners and researchers who have participated in its project and the very supportive nature of the multi-stakeholder groups. Consequently, the Expert Panel strongly suggests expanding on the work of this project to cooperatively develop a more comprehensive guidance note, supported by the urban development industry and regulators, for planning and designing urban developments in high groundwater areas. Such guidance could be incorporated into existing processes and documents, such as those associated with *Australian Rainfall and Runoff 2019*, and/or build on those of the IPWEA, noting, for example, that IPWEAWA has produced a *Specification for separation distances for groundwater-controlled urban developments 2016*. The guidance note could usefully include a short series of case studies and worked examples to help explain a methodology and why it is reasonable in each particular case. Such a guidance note could also be used to inform and, for relevant parts, be incorporated into initiatives such as Design WA, currently being developed by the Western Australian Planning Commission.

6. Summary and conclusions

Improving the methods used to mitigate the presence of high groundwater in urban developments offers the potential for dramatic improvements to the status quo for developers, residents, Local Government and the natural environment. It is worth working to improve processes and outcomes in this arena.

High groundwater sites vary in the risks they pose to residents, Local Government or the natural environment following urban development. These risks provide a framework for selecting groundwater investigation, modelling and assessment methodologies. The higher the risk, the more sophisticated the methodology should be.

Regardless of model sophistication, there are pervasive uncertainties regarding model parameterization. In particular, pre-development evaporation and transpiration are very poorly understood (the Expert Panel is aware of one measurement site on the Swan Coastal Plain), and post-development gross recharge rates are also poorly understood. In the absence of improved understanding of these processes - which force all models - there will be uncertainty associated with any and all modelling output. This is particularly true for models attempting to make forecasts under future climatic conditions.

Therefore, additional research is needed to develop an improved understanding of gross recharge in urbanised environments and of evaporation and transpiration in pre-development locations. This research should be coupled with design innovations that can reduce the risks of groundwater flooding and provide robustness to model uncertainty.

Although challenges remain in managing development in high groundwater environments, the Expert Panel was tremendously impressed and heartened by the commitment, goodwill and engagement of a very broad suite of stakeholders in addressing these challenges. We hope that this Report forms a useful contribution to minimising risks to the built and natural environments, and to maximising the opportunities for innovation, resource recovery and creativity that the challenge of high groundwater also provides.

7. References

Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, and Testoni I, (Editors) (2019) Australian Rainfall and Runoff. A Guide to Flood Estimation. Commonwealth of Australia (Geoscience Australia), Barton, ACT, Australia

Barr A. and Barron O. 2009. Application of a coupled surface water-groundwater model to evaluate environmental conditions in the Southern River catchment. CSIRO: Water for a Healthy Country National Research Flagship

Barnett B, Townley LR, Post V, Evans RE, Hunt RJ, Peeters L, Richardson S, Werner AD, Knapton A and Boronkay A. 2012. Australian groundwater modelling guidelines, Waterlines Report, National Water Commission, Canberra, Australian Capital Territory

Barron OV, Barr AD, and Donn. MJ, Effect of urbanisation on the water balance of a catchment with shallow groundwater. Journal of Hydrology (2013) 485: 162-176

Baskar AS, Beesley L, Burns MJ, Fletcher TD, Hamel P, Oldham CE, and Roy AH. Will it rise or will it fall? Managing the complex effects of urbanisation on base flow. Freshwater Science. (2016) 35 (1): 293-310. The Society for Freshwater Science

CRCWSC (2017) Project IRP5. https://watersensitivecities.org.au/content/project-irp5/.

CRCWSC (2019) Mind the gap–what we don't know about urban areas with high groundwater. Cooperative Research Centre for Water Sensitive Cities, Melbourne, Australia

Davies, C; Oldham, C and Vogwill, R. Urban subsurface drainage nutrient quality assessment [online]. In: 10th International Conference on Water Sensitive Urban Design: Creating water sensitive communities (WSUD 2018 & Hydropolis 2018). Barton, ACT: Engineers Australia, 2018: 37-46.

Department of Environment Regulation (2015 - 1) Identification and investigation of acid sulfate soils and acidic landscapes. Government of Western Australia. Perth, Western Australia

Department of Environment Regulation (2015 – 2) Treatment and management of soils and water in acid sulfate soil landscapes. Government of Western Australia. Perth, Western Australia

Department of Water (2007) Stormwater Management Manual for Western Australia, Government of Western Australia, Perth, Western Australia

Department of Water (2008) Urban water management plans. Guidelines for preparing plans and for complying with subdivision conditions. Government of Western Australia. Perth, Western Australia

Department of Water (2009) Xu C, Canci M, Donnelly M, and Stokes R. Perth Regional Aquifer Modelling System (PRAMS) model development: Application of the Vertical Flux Model. Hydrogeological record series. Report No HG27. February 2009. Government of Western Australia. Perth, Western Australia

Department of Water (2013) Water resource considerations when controlling groundwater levels in urban development. Government of Western Australia, Perth, Western Australia

Fan, Ying, H. Li, and Gonzalo Miguez-Macho. Global patterns of groundwater table depth., *Science* 339.6122 (2013): 940-943.

GHD, Water Technology, and The University of Western Australia (2018) Integrated Research Project 5: Knowledge based water sensitive solutions for development in high groundwater environments. Stage 1 report. Cooperative Research Centre for Water Sensitive Cities, Melbourne, Australia

Harlow, N. and Coate, B.D. (2004) Plants and landscapes for summer-dry climates of the San Francisco Bay region. East Bay Municipal Utility District.

IPWEA (2016) Specification Separation distances for groundwater controlled urban development. Perth, Western Australia

IPWEA (2017) WA Local Government Guidelines for Subdivisional Development. Institute of Public Works Engineering Australasia Western Australia Incorporated, Perth, Western Australia

Locatelli L, Mack O, Mikkelsen PS, Arnbjerg-Nielsen K, Deletic A, Roldin M, and Binning PJ. Hydrologic impact of urbanisation with extensive stormwater infiltration. Journal of Hydrology (2017) 544: 524-537

Minnesota Stormwater Manual contributors (2019) Minnesota Stormwater Manual. https://stormwater.pca.state.mn.us/index.php?title=Main_Page. Accessed 18 December 2019
Moftakhari, H.R., AghaKouchak, A., Sanders, B.F. and Matthew, R.A. (2017), Cumulative hazard: The case of nuisance flooding. Earth's Future, 5: 214-223. doi:10.1002/2016EF000494
New WAter Ways (2019) Current state of water related knowledge for development in areas of high groundwater. Water Sensitive Urban Design Fact Sheet. August, 2019. www.newwaterways.org.au
Ocampo CJ (2018) The impact of urbanisation on water balances and nutrient pathways in areas of high groundwater: A review of recent literature. Hydrology and nutrient transport processes in groundwater/surface water systems (Project B2.4). Cooperative Research Centre for Water Sensitive Cities, Melbourne, Australia
Ocampo et al. (2017) Performance of two urban stormwater biofilters in an area with seasonally high groundwater. Cooperative Research Centre for Water Sensitive Cities, Melbourne, Australia:
Peel Development Commission (2006) Peel Harvey Coastal Catchment Water Sensitive Urban Design Technical Guidelines, October, 2006
Richardson S, Irvine E, Froend R, Boon P, Barber S, Bonneville B. 2011. Australian groundwater dependent ecosystem toolbox part 1: assessment framework. Waterlines Report. National Water Commission, Canberra, Australian Capital Territory
WAPC (2008) Better Urban Water Management. State of Western Australia, Perth, Western Australia

Appendices

Appendix A. Expert Panel Terms of Reference

Aims

- Formulate Guidance for a process and methodology for urban water management in developments in areas subject to seasonal high groundwater in the Swan Coastal Plain. This will be undertaken through an industry consultation process, drawing on the experience and knowledge of practitioners and researchers working in the region;
- Review relevant research and industry activities (e.g. CRCWSC Project B2.4 literature review, CRCWSC Integrated Research Project Five (IRP5) Stage 1 report and literature review, Western Australia's GW Steering Group and SW Runoff Co-efficient Workshop outcomes) and a number of case studies to identify the technical and/or process barriers that needed to be overcome and the level of certainty behind the selection of modelling assumptions. Modelling assumptions to be considered are to include, but not necessarily be limited to, annual and event-based runoff rates and recharge rates at different scales, evapotranspiration rates and their application in water balance modelling, and stormwater management system (including groundwater impacts) modelling;
- Set the framework for transparency around modelling parameters (eg where the assumptions lie; range in assumptions), including implications for policy; and
- Recommend a way forward to move from subjective to quantitative assessment and reduce margins of error. This can be incorporated into policy and guidelines which are currently under review (provided it is completed within the State Planning Policy review timeframe).

Background

In the absence of some fundamental science, there is a level of debate among WA water management practitioners about whether at least some of the current approaches and assumptions being used for the modelling and management of high groundwater environments in the Swan Coastal Plain are justifiable. This has implications for achieving best practice urban development in such environments, now and in the future. As a result, there is a need for a consistent approach in the Swan Coastal Plain to determining appropriate water management strategies for urban development in such environments.

It is proposed that an independent Expert Panel be established to formulate guidance for the concept planning and design approach to be applied when developing water management strategies for urban development in high seasonal groundwater environments. This guidance will be based around the concept of integrated urban water management. The principal objective of the guidance is to provide consistent methodology and parameters for designing urban developments in areas subject to seasonal high groundwater tables. The guidelines will reflect a consensus approach amongst key stakeholders, moderated by the Expert Panel. It will be based on diagnostics of case studies, drawing on the expertise and tacit knowledge of the Expert Panel.

Statement of Intent

The Expert Panel will consist of a variety of experts, including those with technical knowledge of surface and groundwater interactions, systems and processes, and/or an understanding of the specific high groundwater and urban development issues that are prevalent in WA. Expert Panel members will be independent of, and not hold a conflict of interest – whether real or perceived – with, urban developments and related decisions in WA.

The Expert Panel will have a combination of policy, modelling and science expertise to ensure the guidance that is formulated meets both scientific and practical policy needs. Individually and collectively the members will have the ability (be it knowledge, networks, authority, legitimacy) to inform decision-making and best practice and be able to understand and influence the complex system change processes that are needed to address the existing debates and uncertainties within the WA technical and policy environment.

Activities of the Expert Panel

The Expert Panel will undertake a number of activities including:

A. Review past work and seek submissions and/or hold local "hearings" including site visits on various priority topics/approaches/assumptions that were contested or unclear in Stage 1 of the CRCWSC's IRP5 to identify matters for further investigation by the Panel;
B. Further explore these topics/approaches/assumptions through a review of local case studies to, where possible, test sensitivity, verify assumptions and validate approaches to support best practice;
C. Deliberate areas they are able to resolve and communicate this through a draft document that will be circulated for stakeholder comment;
D. Document uncertainties and, where appropriate, recommend an interim range of values for key modelling parameters, together with a process for reducing uncertainty in the future (including providing guidance on any relevant field validation program), and seek stakeholder comment through collaborative processes;
E. Consider stakeholder comments and prepare an updated guidance document for consideration and publication by the CRCWSC;
F. Attend Expert Panel meetings as follows:
    a. Meetings to be held on an as needed basis at the discretion of the Chair of the Expert Panel. Excluding any local "hearings", this is likely to be monthly;
    b. The duration of the Panel will be limited to 8 months, unless agreed otherwise by the CRCWSC;
    c. Meetings and/or teleconferences of the Expert Panel will be coordinated by the CRCWSC Executive and will include updates and reports to the IRP5 Project Steering Committee (PSC);
    d. It is proposed that Greg Claydon be the independent Chair of the Expert Panel.
G. Guide the development of the field validation program as part of Work Packages 2 and 3 of Stage 2 of IRP5.

Appendix B. Expert Panel Methodology

The analysis conducted by the Expert Panel consisted of two distinct phases. First, a review of the recent literature and available guidance aimed at identifying the *status quo* and current knowledge gaps. The review focused on topics/approaches/assumptions that were contested or unclear in Stage 1 of the CRCWSC's IRP5 Scoping Study. The documents reviewed and key findings are reported in Appendix D.

The second phase of the Expert Panel's approach consisted of a series of qualitative case studies to identify the technical and/or process barriers, and build an understating on current practices across the industry. Given the in-depth, qualitative nature of the research, non-probability sampling methods were used, which are most appropriate for exploratory studies. In particular, purposeful sampling was employed to identify individuals and organizations who are patricianly knowledgeable about high groundwater in urban areas across the Swan Coastal Plain. Selection of participants was also made on the basis of their ability and willingness to voluntarily and anonymously participate and communicate in an effective, articulate manner (Palinkas et al. 2015).

It is understood that the accuracy and quality of practitioners' work in relation to urban planning and impact varies widely, which was reflected in the sampling process. Hence, case studies were selected in three broad categories: a) examples of industry best-practices that could serve to inform the guidance note to be developed by the Expert Panel; b) examples of most commonly applied practices across the industry; c) examples of practices that can be improved. Further, to understand the perspective of various stakeholder groups, case studies were conducted with the following participants: regulators and resource managers, Local Government authorities (i.e. cities and shires), consultants to the urban development industry and research academics.

Prior to considering the case studies, participants were notified of the questions to be discussed, which allowed them to prepare the materials to be presented. Questions were as detailed in Appendix C and all questions did not necessarily apply to all case studies and all participants.

The case studies were generally carried out in the format of presentations by participants, followed by semi-structured interviews. The open-ended nature of the questions enabled participants to provide narrative answers, and thus provide new insights, which may not have been previously identified by the Expert Panel. Data were collected in the form of presentation transcripts and notes in relation to specific questions. In addition, written materials, such as reports and presentations, were collected. Descriptive data were analysed using a qualitative approach. First, narratives were classified into common themes, following thematic analysis (Braun and Clarke 2012). Second, participant's responses were reviewed to identify information to fill the existing knowledge gaps and identify questions that warrant further research.

Appendix C. List of questions for participants

Additional Information to Guide Participant Presentations

Scope of Presentation and Discussion

The Expert Panel requests that participants make a presentation that covers in detail one urbanisation project in an area impacted by high groundwater, preferably, but not necessarily, a project that has already received planning/environmental approval (i.e. a “success” story). By doing a “deep dive” on these projects as case studies, we hope to augment the more general picture provided to the CRCWSC during previous consultations.

The Expert Panel requests that the participants use their presentation to describe in detail the technical approaches used to assess and/or predict the impacts of the proposed development on the site water balance and related topics (e.g. water resources, flood/waterlogging risks, nutrient pathways if relevant, impacts on sensitive environments etc).

The Expert Panel is interested to learn about the overall methodology, as well as such details as the conceptual and numerical models used, their parameterization, calibration and testing or validation, as well as major sources of uncertainty and how they were addressed.

Following the presentations the Expert Panel will facilitate a technical discussion based on the information that participants offer in their presentations, and aiming to clarify and deepen the Panel’s understanding of the methods used by the participants.

Guide for the Presentation

The Expert Panel requests that participants cover the following topics in their presentations (although the list below is not intended to be exhaustive, and we recognise that not all topics will be relevant to all projects/participants):-

- **Project background**:
    - Type, purpose of project/case study
    - Its status
    - Special features (eg “routine” or “innovative” – how and why, scrutiny from planners/regulators/industry/community, other features of particular note)
    - Reason for presenting this project.
- **Physical and environmental context**:
    - Description of the project site – catchment areas and condition, topography, soils, vegetation, land and water uses, groundwater levels, infrastructure and other physical features considered relevant pre and for post development
    - Prior availability of data and information relevant to water management, nutrient management, and other environmental management factors
    - Nature of the high groundwater challenges faced in the project (e.g. water disposal, water supply, proximity to sensitive environments like wetlands) and how those challenges influenced the approach taken to the project.

- **Overall project methodology**:
    - Overall technical approach used to assess and/or predict the impacts of the proposed development and reasons for selecting it
    - Alternative approaches considered and reasons for not selecting them.
- **Modelling approach**:
    - Modelling approach used in the project and reasons for selecting it
    - Alternative approaches considered and reasons for not selecting them.
- **Model structure**:
    - Components of the model (or other predictive tools used)- what physical and biological processes does it capture, and how does it describe them?
    - Description of how the model represents space (e.g. gridded, semi-distributed, lumped); heterogeneity (e.g. in land cover, soil/aquifer properties, plant water uptake, etc.); specific urban infrastructure and processes (e.g. pipelines, rainwater tanks, infiltration galleries, building foundations, pumping for irrigation, etc.)
    - Hydrological processes that were difficult but important to represent in the model and any work-arounds adopted to cope with them.
- **Model parameters**:
    - Variables that required parameterization
    - Variables that were most important to get right for good results
    - Approach taken for each parameter (e.g. use of default values, use of literature values, use of values based on expert knowledge, use of calibration, use of other "evidence")
    - Where relevant, description of the calibration approach used (e.g. observation(s) calibrated to, and parameters allowed to vary in the calibration).
- **Model predictions**:
    - Methods used to characterise uncertainty in model predictions and the extent and results of any sensitivity testing undertaken
    - Modelling processes that were particularly influential to the hydrology of the project
    - Overall confidence in the modelling results and reasons for that level of confidence.
- **Model satisfaction/improvements**:
    - Reflections on the suitability of the modelling platform used, and the modelling methodology employed
    - Suggestions for improvement to the modelling platform and the modelling methodology

- Suggestions for additional measurements to be available for model forcing/testing/calibration for this project
- Suggestions for the most important factors for the Expert Panel to provide guidance and recommendations on.

Appendix D. Summary of literature

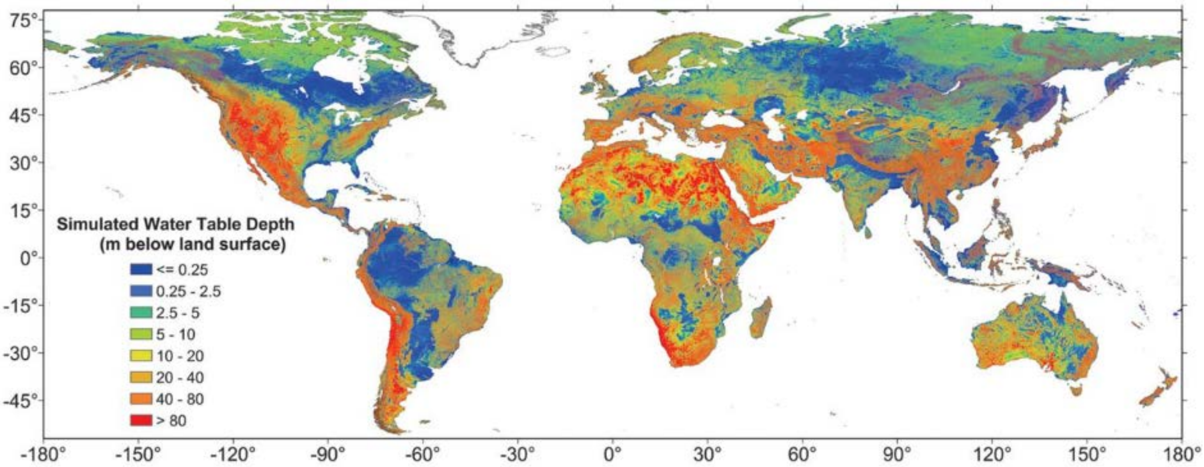


Figure D1. Global simulated depth to groundwater (Fan et al 2013)

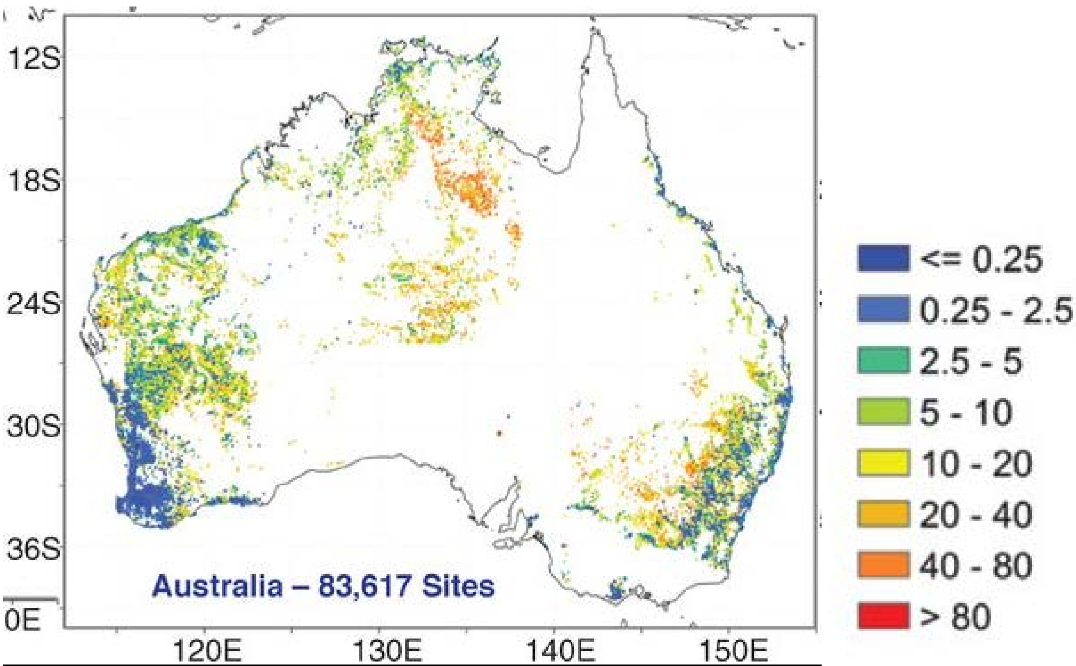


Figure D2. Depth (m) to groundwater in Australia

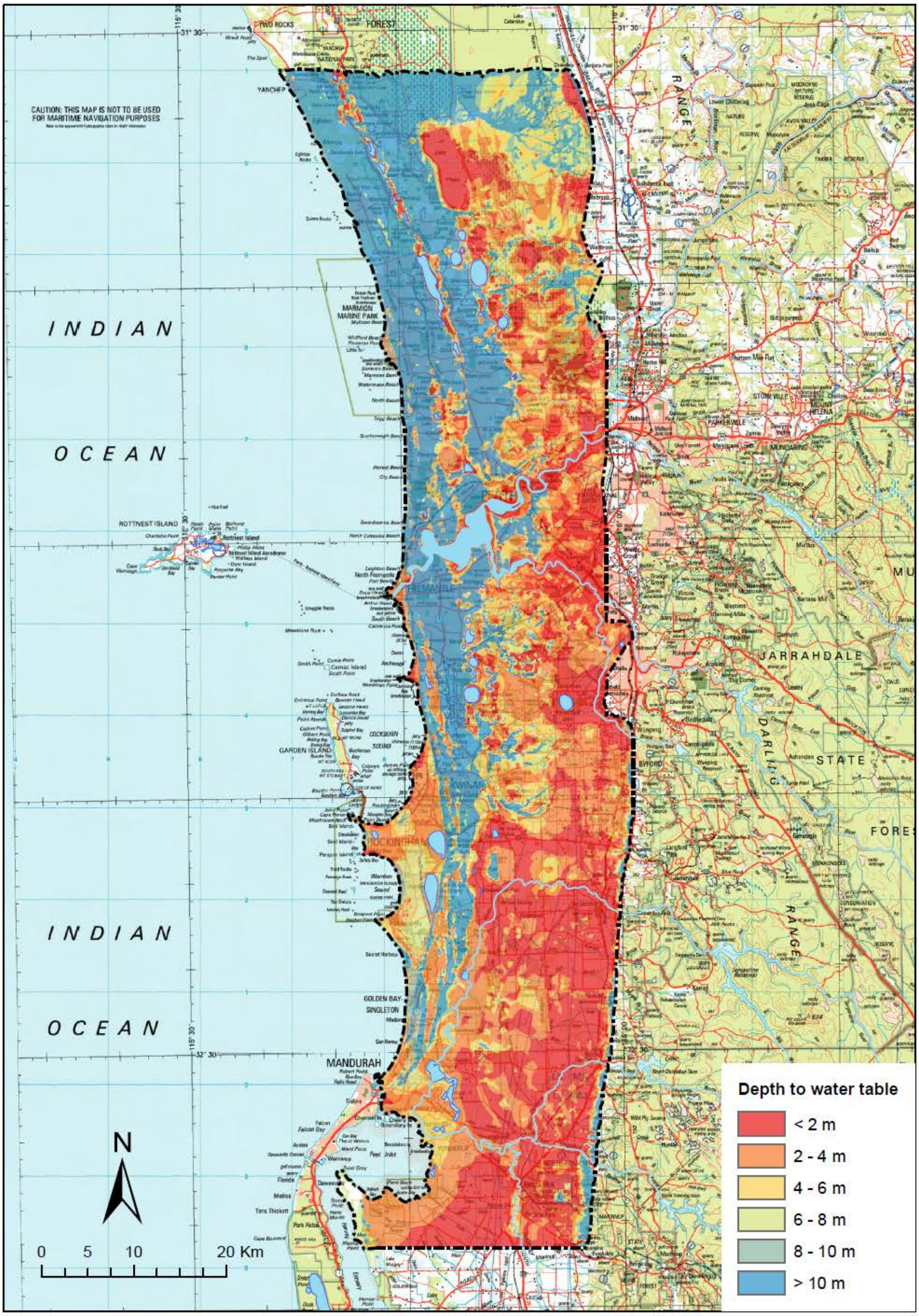


Figure D3. Depth to groundwater across the Swan Coastal Plain

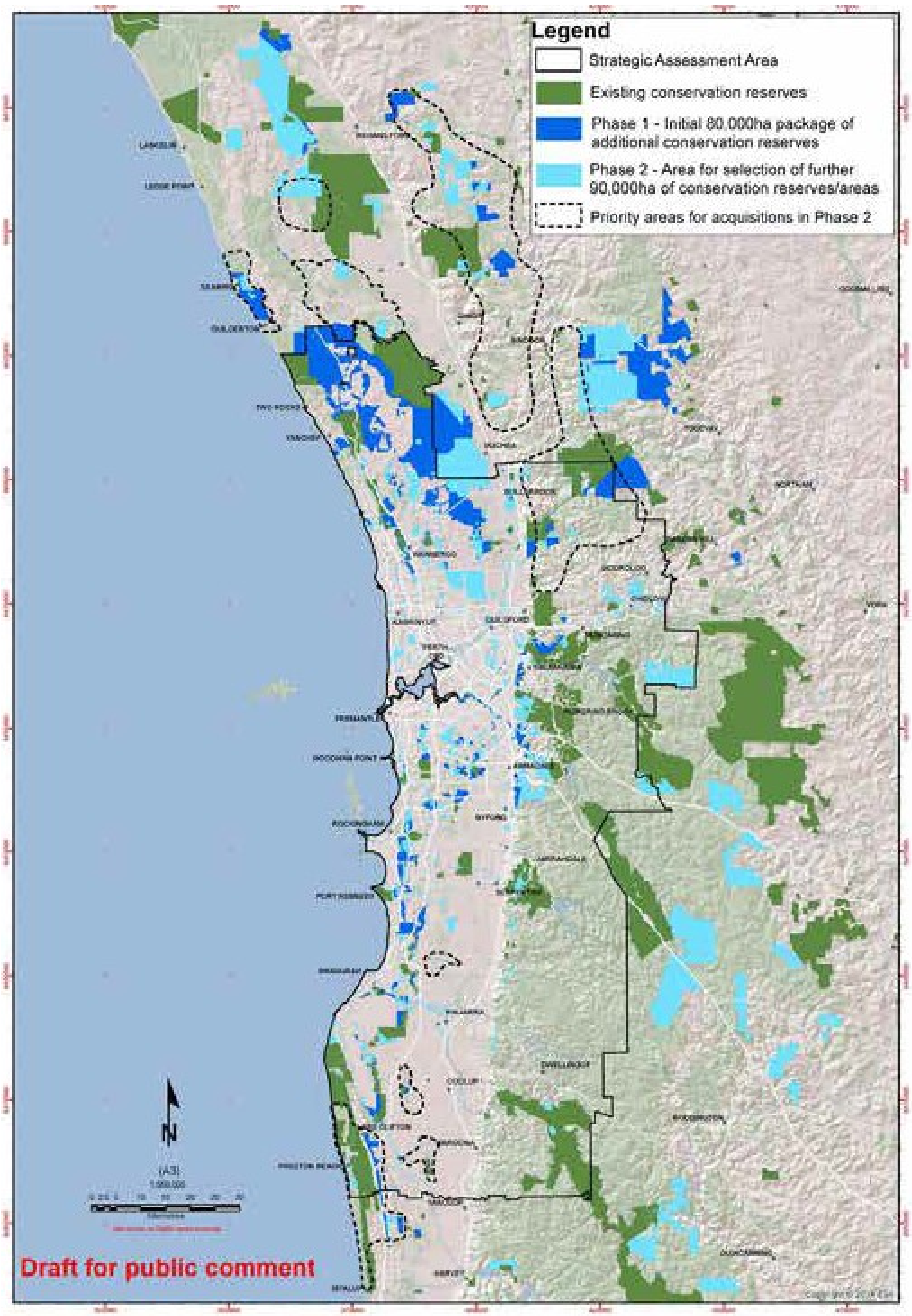


Figure D4. Intersection of future urban growth with areas of high groundwater on the Swan Coastal Plain

The impact of urbanisation on water balances and nutrient pathways in areas of high groundwater: A review of recent literature

As part of the project *Hydrology and nutrient transport processes in groundwater/surface water systems Project B2.4* (CRCWSC 2019), a comprehensive literature review was carried out (Ocampo 2018). This examined over 100 journal articles on water and nutrient balances in urban areas with high (shallow) groundwater and significant groundwater-surface water interaction. While water sensitive urban design (WSUD) is often recommended to offset the impact of urbanisation, in areas of high groundwater, it is still not well understood how such systems impact high water tables, how additional infiltrated water travels underground and how these processes impact nutrient loads in water bodies. Thus, the purpose of the literature review was to gain an understanding of the current status of the knowledge and remaining gaps on two key questions:

i) the effects of urbanisation and stormwater practices on the water balance and hydrological processes of the urban subsurface;

ii) the implication of these processes for the fate and transport of nutrients along subsurface pathways in areas with high groundwater.

The review focused on case studies with processes specifically affecting unsaturated zone hydrology and the high, unconfined groundwater balance, over short time scales (a few days to weeks). The studies included cases sharing certain similarities with Perth, e.g. soil, rainfall and high water table (less than 4m deep).

The literature concludes that, while the areas of stormflow modelling (surface hydrology) and groundwater modelling (hydrogeology) are well-developed, the lack of understanding around surface-groundwater interactions hinder accurate predictions of changing water balances and nutrient export under urbanisation. The review identified four key knowledge gaps, as described below.

- **Infiltration in the urban mosaic**. Typically, coupled groundwater–surface water models estimate infiltration rates from 24-hour totals, which can be much lower than transient rates at the onset of an event. Thus, infiltration is often underestimated, particularly for short duration rainfall events. Further, urban water balances often do not account for infiltration through cracks and joints in hard impervious areas. The literature suggests up to 50 per cent of impervious areas should be considered as previous, although there is insufficient supporting data.

- **Recharge of groundwater from rainfall events.** Large discrepancies exist in the recharge in urban areas with high water tables, with recent improved estimates being larger than previously thought. In particular, lawns produced 10 times less recharge that source control systems (SCSs), whose recharge rates are up to 40 per cent more than previously estimated.

- **Interflow processes and delivery mechanisms.** In areas with high water tables where SCSs are used, it was found that density, location and materials of SCSs affected water mounding and its relaxation (return to pre-event levels). Further, water that recharges the high aquifer returns to the stream, affecting its hydrology, hydrochemistry, and nutrient export. Mass balances and multi-technique approaches are cost-effective ways to examine how infiltration sources contribute to interflow and affect nutrient export.

- **Nutrient cycling along subsurface flow pathways in urban areas.** The review found no comprehensive study reporting nutrient transformations along the subsurface pathway in urban environments. Only studies in tiled agricultural landscapes were found, but the dynamics can be different to those in urbanised areas given the complexity of the subsurface and shorter time scales for nutrient processing.

Based on its findings, the literature review provides **a conceptual model to guide future work in Perth**. This includes

- **Estimate infiltration/exfiltration rates from SCSs** using hydrograph recession analysis. Measure the hydrograph at the surface water storage or filter media storage via continuous water level recordings;

- **Compute recharge rates** and amounts, and report them at a standard depth of 2 metres below ground level. Collect data under hard surfaces, housing built on imported fill and green areas;

- **Undertake interflow monitoring** via hydrometric and environmental tracers to identify the source of infiltration and to quantify groundwater discharge. Conduct monitoring along stormwater drainage pipes to ensure a proper mass balance approach;

- **Use a mass balance approach** along the high groundwater pathway, following control planes and using an integrative mass flux concept. Locate control planes from highland to lowland areas to quantify exposure time and nutrient transformations.

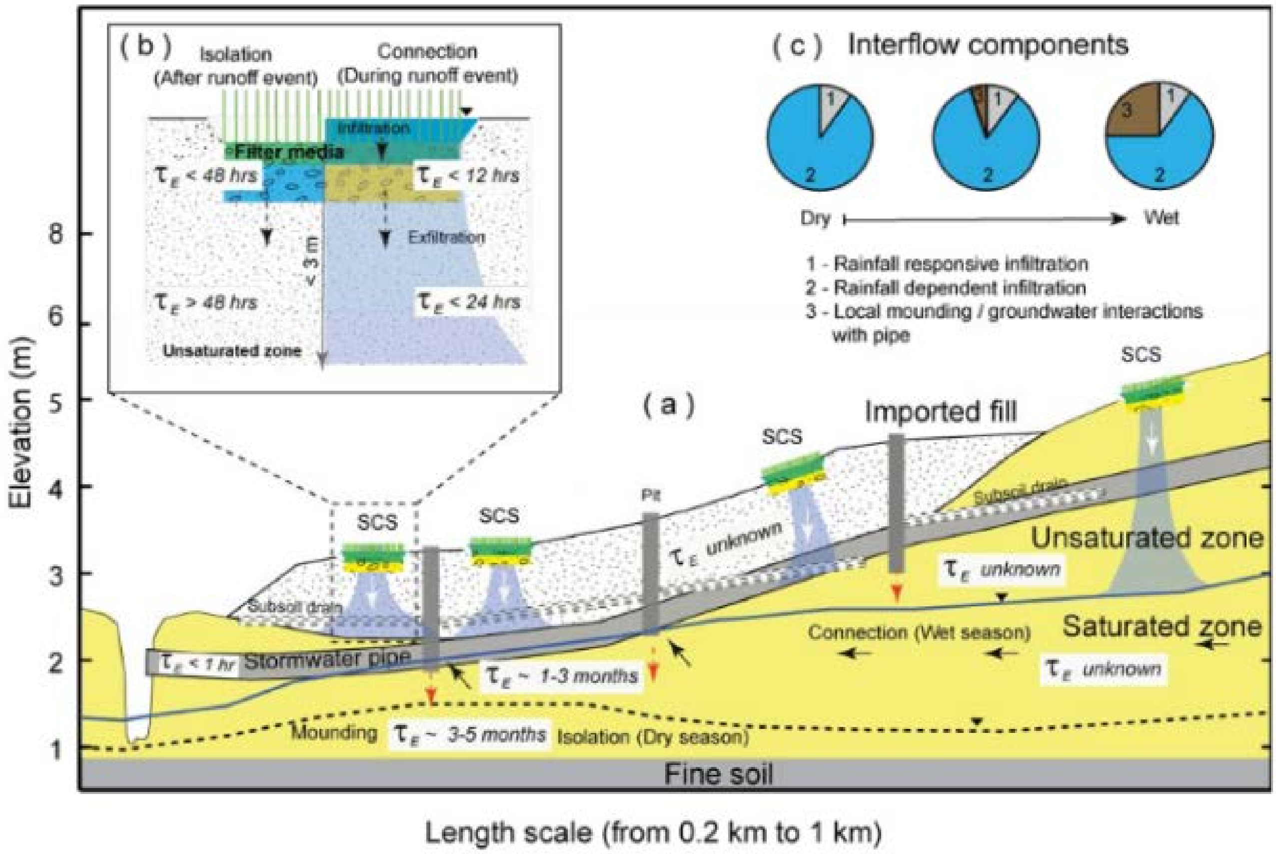


Figure D 5 Conceptual model of hydrological processes and relevant τ_E values for nutrient processing in the urban karst, in areas with high groundwater: (a) landscape representation of current built forms and stormwater management practices; (b) individual SCSs; (c) variation of interflow components over seasonal scales Source: CRCWSC (2019) .

In addition to the literature review summarised above, other studies in WA have found that urbanisation with stormwater infiltration increases recharge and lowers evapotranspiration (Locatelli et al. 2017). As a result, the water table tends to rise and, thus, the probability of groundwater seepage above terrain increases. A comparative study in Perth (WA) and Baltimore (Maryland), developed a decision-support framework to help predict the likelihood and direction of changes in baseflow (Bhaskar et al. 2016). The study (p.293) found how predevelopment water-table height, climate, geology and urban infrastructure interacted such that urbanisation led to a rise in Perth’s baseflow, yet a fall in the case of Baltimore.

Further, a modelling study in the Southern River catchment in Western Australia, showed how urbanisation can significantly reduce evaporation and evapotranspiration (Barron et al. 2013). Because of direct infiltration of roof and road runoff, groundwater recharge rates increase, thus leading to greater discharge flows into the urban drainage system.

Integrated Research Project 5 Stage 1 Report –2018

In 2018, GHD, Water Technology and the University of Western Australia carried out Integrated Research Project 5 (IRP5) Stage 1 - *Knowledge-based water sensitive city solutions for groundwater impacted developments.* The project had four key objectives: 1) Review current state of knowledge; 2) Identify knowledge gaps in urban development design and methodologies; 3) Investigate alternative building/construction/development methods; and 4) Develop an action and research plan to address key knowledge gaps. The project's methodologies included literature review, structured interviews with stakeholders and experts, and a stakeholder workshop. The resulting report (CRCWSC 2019) provides a summary of the findings of Stage 1 of IRP5.

The report highlights the lack of a consistent methodology for determining pre-development groundwater levels within the Swan Coastal Plain. Methods applied vary widely across researchers and practitioners, and include the following: Use of *Perth Groundwater Atlas* (Department of Environment 2004); Average Annual Maximum Groundwater Level (AAMGL) – although this is not endorsed by the Department of Water (Department of Water 2013); and Back-calculation of recent measurements towards historical maximums. Further, numerical models for the estimation of groundwater levels typically fail at the local levels, as they entail uncertainties of 2-10 meters in hydraulic levels. While such uncertainty may be acceptable for regional models, it is excessive for civil structure design. Uncertainties commonly originate from parameters that are difficult to measure (e.g. spatially very variable), or processes whose complex behaviour requires simplification.

To illustrate water balances pre and post development, the IRP5 Stage 1 Report provides a diagram sourced from Ocampo (2018) (Figure D5 below). It is understood that, in Western Australia, urbanisation often causes increases in groundwater levels due to higher post-development net recharge rates. This can be a result from decreased evapotranspiration and increase in infiltration through the provision of soakwells, biofiltration or rain gardens. Post-development groundwater levels can also rise or fall in response to the construction of underground structures (e.g. subsoil drains). Importantly, urban development has the potential to impact water-dependent ecosystems through changes in water levels, mobilisation of nutrients or introduction of pollutants,

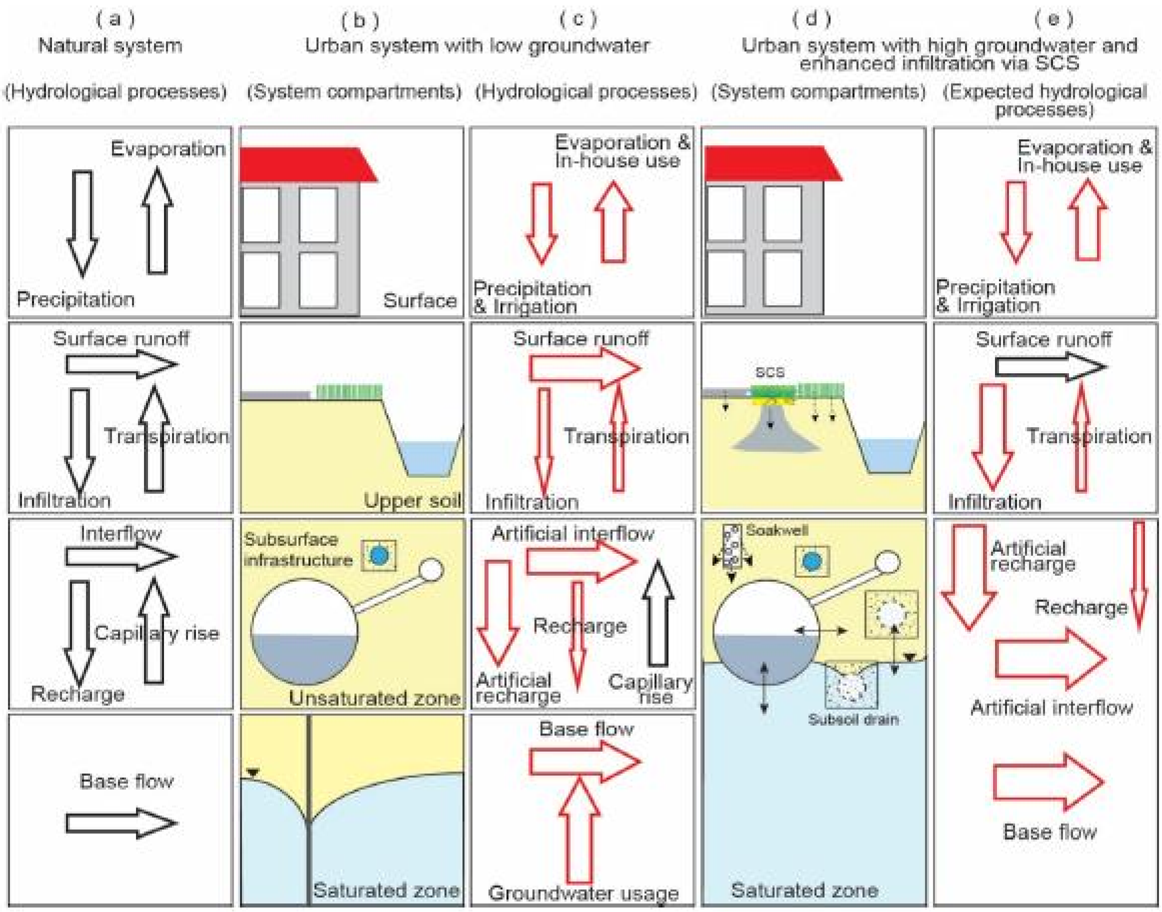


Figure D6. Conceptual model of perturbation of the urban water balance. Red arrows represent water flow that has been modified or introduced by urbanisation or proposed urbanisation in high groundwater environments with SCSs

Groundwater table rise may cause several impacts on infrastructure and buildings, including reduction of soil bearing capacities and strength of concrete, damage to pavement and other structures, as well as infiltration into sewage systems. Hence, management measures to deal with high groundwater are a requirement of the Building Code of Australia (Housing Industry Association 2019) and are addressed by Australian Standard AS 2870-2011. In addition, fill material, drainage and alternative construction methods can be used to manage adverse impacts of high groundwater.

This report identified 27 contested and 6 unknown knowledge areas, clustered around infiltration and recharge rates; evapotranspiration rates, groundwater fluxes; and groundwater levels. Poor understanding of pre-and post- development water balance results in impeded ability to protect current hydrologic cycles and a risk of the development negatively impacting infrastructure, property and the receiving environment. As a result, the IRP5 Stage 1 Report concludes that Stage 2 research should address the following fundamental water balance and water quality knowledge gaps:

- Pre- and post-development infiltration and recharge rates;
- Pre- and post-development evapotranspiration rates;
- Post-development pollutant pathways and nutrient cycles.

References for Appendix D

Barron, O. V., Barr, A. D., & Donn, M. J. 2013. 'Effect of urbanisation on the water balance of a catchment with shallow groundwater'. Journal of Hydrology, 485, 162-176. doi: 10.1016/j.jhydrol.2012.04.027.

CRCWSC. 2019. 'Mind the gap–what we don't know about urban areas with high groundwater'. Melbourne, Australia: : https://watersensitivecities.org.au/content/mind-the-gap-what-we-dont-know-about-urban-areas-with-high-groundwater/

Fan, Ying, H. Li, and Gonzalo Miguez-Macho. Global patterns of groundwater table depth., *Science* 339.6122 (2013): 940-943.

GHD, Water Technology, & The University of Western Australia. 2018. 'Integrated Research Project 5: Knowledge based water sensitive solutions for development in high groundwater environments. Stage 1 report.'. Melbourne, Australia: https://watersensitivecities.org.au/wp-content/uploads/2018/07/att10_IRP5_Stage1-version2.pdf

Locatelli, L., Mark, O., Mikkelsen, P. S., Arnbjerg-Nielsen, K., Deletic, A., Roldin, M., et al. 2017. 'Hydrologic impact of urbanization with extensive stormwater infiltration'. Journal of Hydrology, 544, 524-537. doi: https://doi.org/10.1016/j.jhydrol.2016.11.030.

Ocampo, C. J. 2018. 'The impact of urbanisation on water balances and nutrient pathways in areas of high groundwater: A review of recent literature'. Melbourne, Australia. Hydrology and nutrient transport processes in groundwater/surface water systems (Project B2.4): https://watersensitivecities.org.au/content/urbanisation-and-stormwater-management-practices-on-water-balances-and-nutrient-pathways-in-areas-of-high-groundwater/

Appendix E. Examples of international approaches to manage high groundwater in urban areas.

This section has been developed with supporting information provided by Carl Davies, as part of the PhD Thesis "Subsurface drainage for sustainable urban development" (Davies in preparation).

Constructed wetlands and wet ponds

Constructed wetlands and wet ponds are a common practice to management of stormwater in coastal plain urban communities across the United States (Chesapeake Stormwater Network 2009). A key advantage is that excavated materials on site can be used as fill to elevate the terrain, where the development will be built. However, in areas of high groundwater, wet ponds can be strongly impacted by the water table and have limited capacity for nutrient removal (Sønderup et al. 2015). In fact, without adequate maintenance, wetlands and ponds designed to manage stormwater can result in poor water quality conditions, such as algae blooms, mosquito breeding and odours (EPA 2009). Two examples of the use of constructed wetlands and wet ponds in the USA are urban areas in South East Florida and the Chesapeake Bay Watershed, on the East Coast.

Southeast Florida

South East Florida is characterised by low-lying terrain and a high groundwater table, which rises rapidly in response to heavy rainfall (Czajkowski et al. 2018). Occasionally, in preparation for large storm events, groundwater levels are lowered to increase the unsaturated zone storage. However, due to the risk of sea water intrusion, a continuous management strategy is to control canal water levels to maintain a positive gradient that recharges the aquifer with freshwater. The dual risk of flooding and seawater intrusion is specially significant in urban areas of South Florida's east coast, such as Miami, Palm Beach and Broward (Sukop et al. 2018). Importantly, many residents of Southeast Florida depend on a highly transmissive superficial aquifer as their main source of drinking and irrigation water (Czajkowski et al. 2018). Further, the area is home to environmentally sensitive areas, especially the Everglades wetlands.

Traditionally, Southeast Florida has relied on detentions systems, as one of the key strategies for stormwater and flood risk management (Peluso & Marshall 2002). These include wet or dry detention ponds and constructed wetlands. Dry ponds remain usually dry between rainfall events and are considered effective in removing suspended solids, but not for the treatment of nutrients. In addition, they are not recommended for wetlands, floodplains or very large drainage areas (> 100 ha). Wet detention ponds maintain a permanent pool of water and store urban runoff for hours or days, before controlled release. Nutrients can be partially removed through biological activity in the vegetation, yet a risk of algae blooms and mosquito breeding remains. Constructed wetlands, such as the one in Lake Okeechobee (Guardo et al. 1995), typically provide a higher level of treatment, although they require periodic maintenance (Peluso & Marshall 2002). A recent study (Garcia et al. 2020) shows that, in addition to large hydraulic retention times and effective nutrient removal, constructed wetlands can provide multiple environmental benefits, such as carbon sequestration or habitat provisioning. Figure E-1 illustrates a flow equalization basin in Palm Beach County - a reservoir with a 74 Hm^3 holding capacity, which temporarily stores stormwater runoff for release to the Everglades stormwater treatment areas (SFWMD n.d.-a)

Figure E-1: Flow Equalization Basin in Palm Beach County, Florida, flowing into a contributed wetland. Source: SFWMD (n.d.-a)

Chesapeake Bay Watershed, US East Coast

The Chesapeake Bay Watershed covers an area of 166,530 km^2 across the states of Virginia, Maryland, West Virginia, Delaware, Pennsylvania, New York and Washington, DC. The coastal plan is characterised by its flat terrain, high water table and highly altered drainage system (Chesapeake Stormwater Network 2009). Historically, stormwater management in the coastal plan had been designed following the principles applied in the nearby Piedmont plateau, without being adapted to the different hydrological and hydrogeological characteristics. The flat terrain in the Coastal Plain lacks enough head to effectively move water out of the conveyance system (Chesapeake Stormwater Network 2009). More recently, human activities in the Chesapeake Bay Watershed have resulted in further challenges for storm and groundwater management, including the extensive use of drinking water wells and septic systems, and urban development over areas where (previously) animal manure had been widely applied.

Wet ponds - permanent pools of standing water - are one of the oldest and most widespread forms of stormwater management in the Chesapeake Bay coastal plain (Chesapeake Stormwater Network 2018). One of the main reasons is the advantage of obtaining sediments from on-site excavations, which can then be used as fill elsewhere in the development site. The resulting excavation can be built into a pond to temporarily store floodwater. However, given that most ponds are excavated below the water table, they become influenced by groundwater. This results in diminished nutrient removal capability, limited runoff reduction and frequent nuisances from stagnant water (Chesapeake Stormwater Network 2009 p. 6).

Figure E2 Wet pond in Virginia, within the Chesapeake Bay Watershed Source: Chesapeake Stormwater Network (2018)

While wet ponds are commonly used, the Chesapeake Bay Watershed (Chesapeake Stormwater Network 2009) identified a wide range of potential stormwater management practices. These are grounded into three categories, based on their suitability. First, *preferred* practices are those that are feasible at most developments in the coastal plain and have high flow and/or nutrient management capacity. Preferred practices include constructed wetlands, bioretention, rain tanks, wet swales (except for residential areas), dry swales, rooftop disconnection (lots < 557 sqm), permeable pavement and filter strips. Second, *acceptable* practices are those that are widely applicable, yet require major design adaptations and/or have reduced capability to reduce pollutants. Acceptable practices comprise filtering, urban bioretention, small scale infiltration, compost amendments, green roofs and wet ponds. Finally, *restricted* practices have limited feasibility and poor pollutant removal capacity. These include extended retention ponds, grass channels and large-scale infiltration.

Combined surface and groundwater management

The Netherlands is a highly urbanised country, with 95% of its population living within 50km from the coast (EuroStat 2013). Two-thirds of the land lies below the sea level, while many urban and agricultural areas have been reclaimed from swamps and lakes, thus resulting in severe changes to the natural hydrological environment (Yu et al. 2018). Across the eastern (coastal) half of the country, the groundwater is at surface, and excess precipitation (300 mm/a) is discharged through artificial drainage systems (de Vries 2007). Every year, close to 2 Hm^3 of fresh groundwater is extracted, 60% of which is used for public water supply.

A traditional water management strategy in areas of high groundwater in the Netherlands, including the greater Amsterdam city area, consists of diking and draining lakes through small regulated catchments, referred to as *polders* (Yu et al. 2018). The water level within *polders* is controlled by pumping water into regional drainage canals, called *boezem*s, which in turn can drain into outlets or ditches. Within the regulated catchments (*polders*), water can be purposely managed in one direction or another, alternating with wet and dry conditions. In times of high water demand, water is let to flow from the *boezems*, into the *polder* ditches by gravity, as shown in Figure E 3 (a). Conversely, during periods of precipitation excess, water can be pumped from within the small catchment and into the *boezem* Figure E3 (b). Importantly, draining of *polders* has led to ground subsidence, resulting in higher groundwater seepage rates, which, in turn, requires higher pumping rates to maintain the water level within the *polder*. Further, groundwater seepage substantially affects surface water quality through the introduction of brackish, alkaline, and nutrient-rich water (Yu et al. 2018).

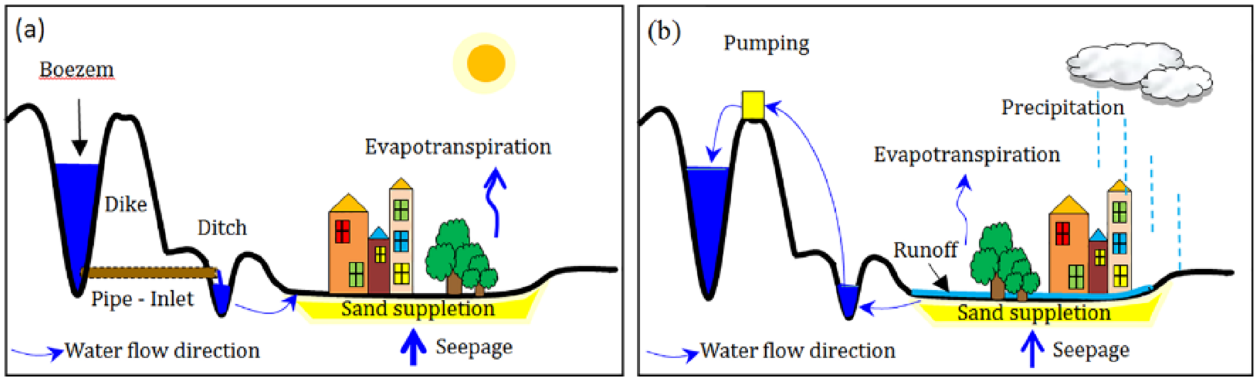


Figure E3. Conceptual model of water management in a *polder* during periods of water deficiency (a) and surplus (b) Source: Yu et al. (2018)

An enhanced approach to the *polder* system consists of the use of subsurface drainage systems that collect storm and groundwater, to be then discharged into the ditches. This system helps prevent wet cellars or flooding of residential areas (Yu et al. 2019), and reduces the need for fill to elevate new developments (Davies in preparation). An example is polder Geuzenveld, located in the western part of Amsterdam (Yu et al. 2019), as shown in Figure E 4.

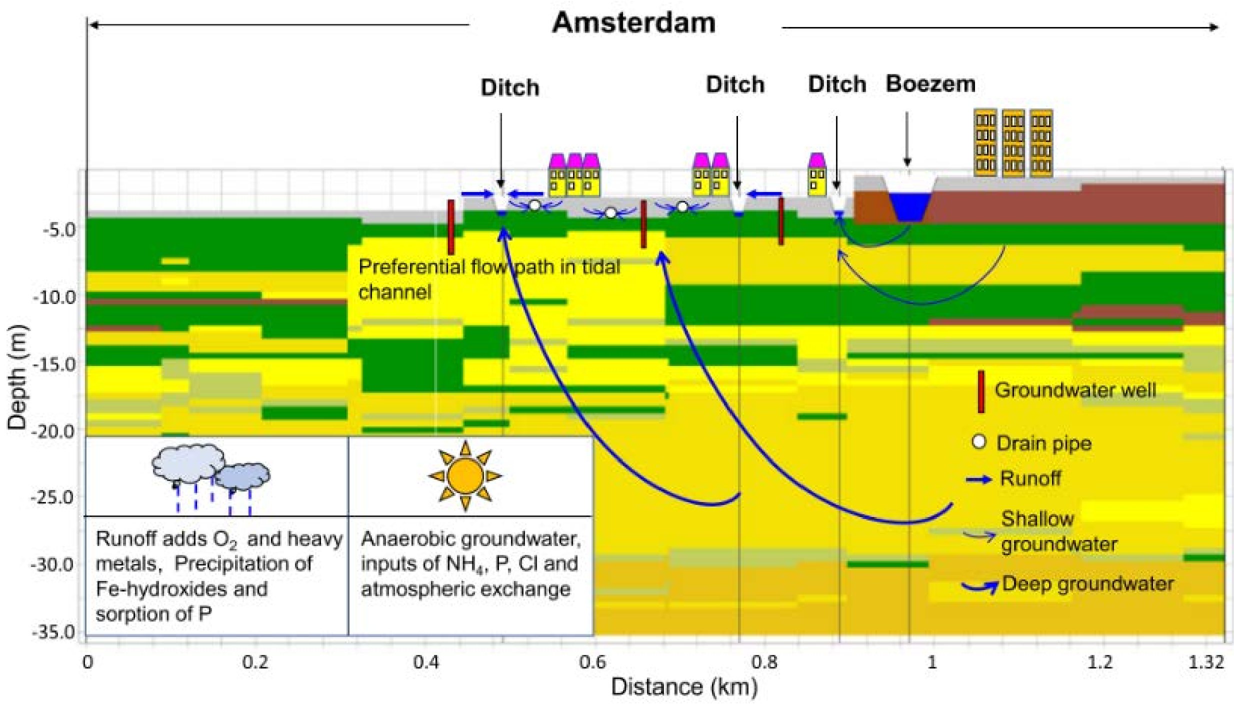


Figure E4. Conceptual model of water fluxes in a *polder* system with subsurface drainage Source: (Yu et al. 2019)

Subsurface drainage and pumping

South Dunedin, New Zealand

South Dunedin urban area (New Zealand) is located in a low-lying area, which had been reclaimed from coastal dunes and marshes (Rekker 2012). The high-water table (0.3-0.7 m below the ground level) currently poses a risk of restricted drainage (Goldsmith & Hornblow 2016), surface ponding and even liquefaction (Barrell et al. 2014). An important factor resulting in rapid, high rises in the water table is heavy rainfall (Fordyce 2014). Importantly, the groundwater level is also impacted by the water level in the adjacent ocean, both of which have raised circa 20cm over the last 150 years. Because the aquifer is not used as a source for drinking water, it has not been thoroughly investigated (Fordyce 2014). Recognizing the knowledge gap and high groundwater-associated risks, Otago Regional Council (2019) has launched a comprehensive groundwater monitoring program across the Dunedin area.

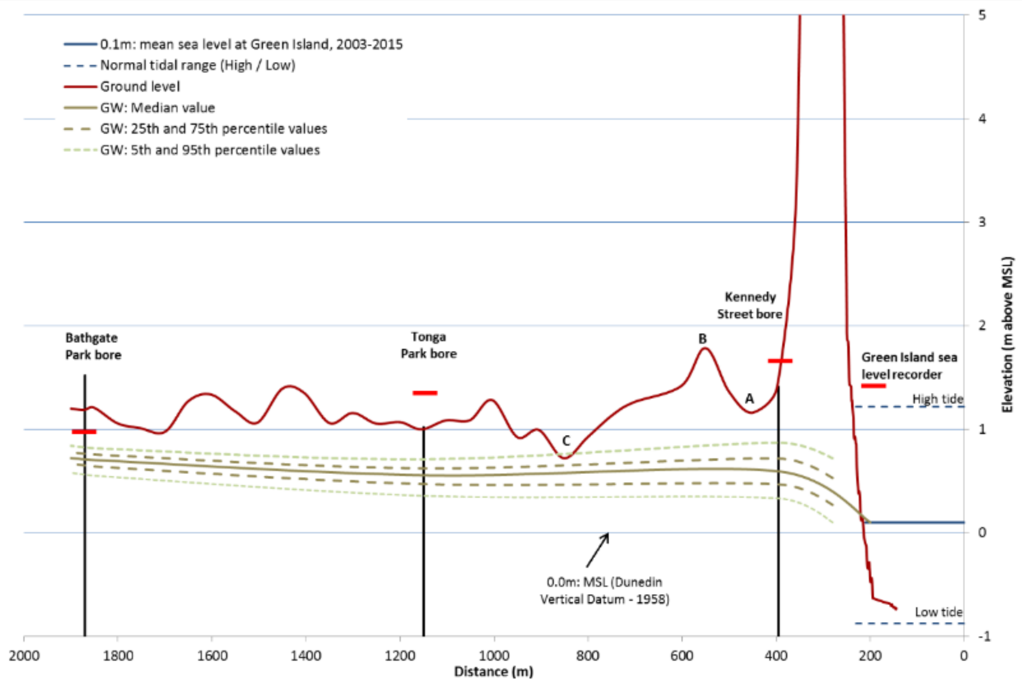


Figure E5. Cross-section from Bathgate Park to the Pacific Ocean (high terrain represents the sea wall) Source: Otago Regional Council (2020)

Given the old age of sewer and stormwater infrastructure, groundwater seeps into the pipes, and drains or is pumped to the sea. Previous investigations have shown “that infiltration of groundwater into the storm and wastewater networks fortuitously helps to suppress the water table, preventing surface ponding under normal conditions” (Goldsmith & Hornblow 2016 p. 28). As sea and groundwater levels rise, current stormwater levels of service may not be met in low-lying areas (Dunedin City Council 2018). A program of asset renewals aims at reducing seepage into pipes, yet it may result in the subsequent groundwater level rise (Goldsmith & Hornblow 2016). Consequently, there could be an increased risk of flooding, surface ponding and damage to infrastructure (Dunedin City Council 2018). A possible strategy to mitigate the rise in groundwater levels consists of installation of additional drainage and pumping equipment. To keep the water table at 2010 levels, the proposed infrastructure upgrade would cost an estimated NZD 75 to 148 million in capital expenditure, and NZD 4 to 18 million in operation and maintenance – for minimum and maximum sea level rise scenarios (Glassey 2018). Other towns in New Zealand, such as Opotiki, in the north island, also experience high groundwater tables and infiltration into sewer systems, as depicted in Figure E 6.

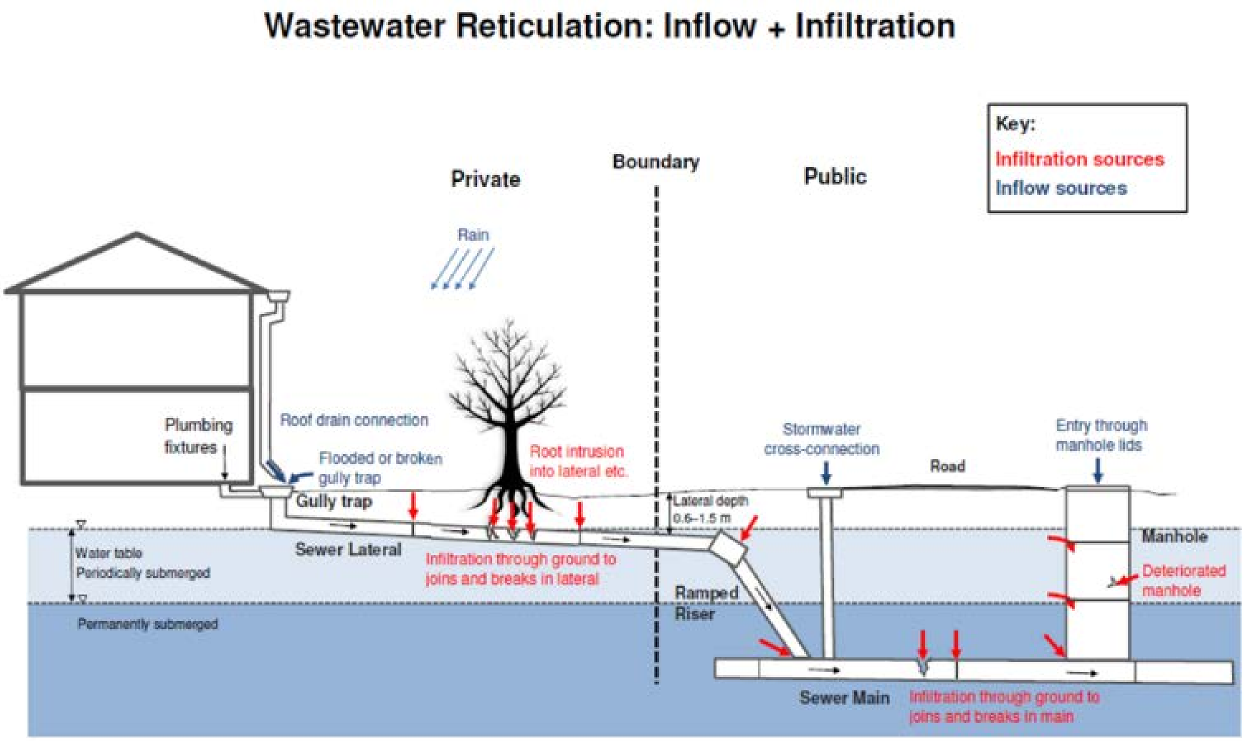


Figure E6. Representation of aged sewer infrastructure in an area of high groundwater Source: Opotiki District Council (2019)

Chañar Ladeado, Argentina

The town of Chañar Ladeado is located in the Santa Fe province of Argentina, circa 400 km west of the capital, Buenos Aires. The town has 5,200 inhabitants and is equipped with a potable water supply system, but no reticulated sewer network (Zimmermann & Riccardi 2000). Following a series of high rainfall years in the 1990s, the water table rose to the surface, flooding cellars and disabling septic tanks. Consequently, a drainage project was designed whereby collector pipes (300mm and 150mm) would be installed parallel to sewer pipes, with the aim to keep the water table at least one meter below the surface. As it is common across areas of low topographic slope in Argentina, subsurface drainage systems typically require pumping stations and channels to discharge the drained water (Zimmermann & Riccardi 2000).

Groundwater pumping for secondary use

The Taipei Basin, in northern Taiwan, contains abundant groundwater resources (Jang et al. 2019). Following rapid economic and population growth in the 1950s and 1960s, groundwater levels dropped by circa 50m, causing subsidence of up to 2.3 m (Jang et al. 2019; Liu et al. 2010). Since 1970, restrictions on groundwater withdrawals have led to a steady recovery of water levels, at 1.3m/year (see Figure E 7). Such high groundwater levels now pose serious risks for underground infrastructure and soil liquefaction. To reduce such risks, previous studies (Liu et al. 2010) have proposed an optimal pumping regime to maintain the water table at least 7.5m below the surface (Liu et al. 2010). This system requires an extensive network of monitoring wells to reflect the state and trend of groundwater levels across the region.

Pumped groundwater can be used for fire control, public open space irrigation and drinking (Jang et al. 2019). More precisely, given the location of water supply plants and different land uses, groundwater extracted in the southern Taipei Basin is for domestic uses, while withdrawals in the eastern Taipei Basin should be restructured to non-potable uses (Jang et al. 2016).

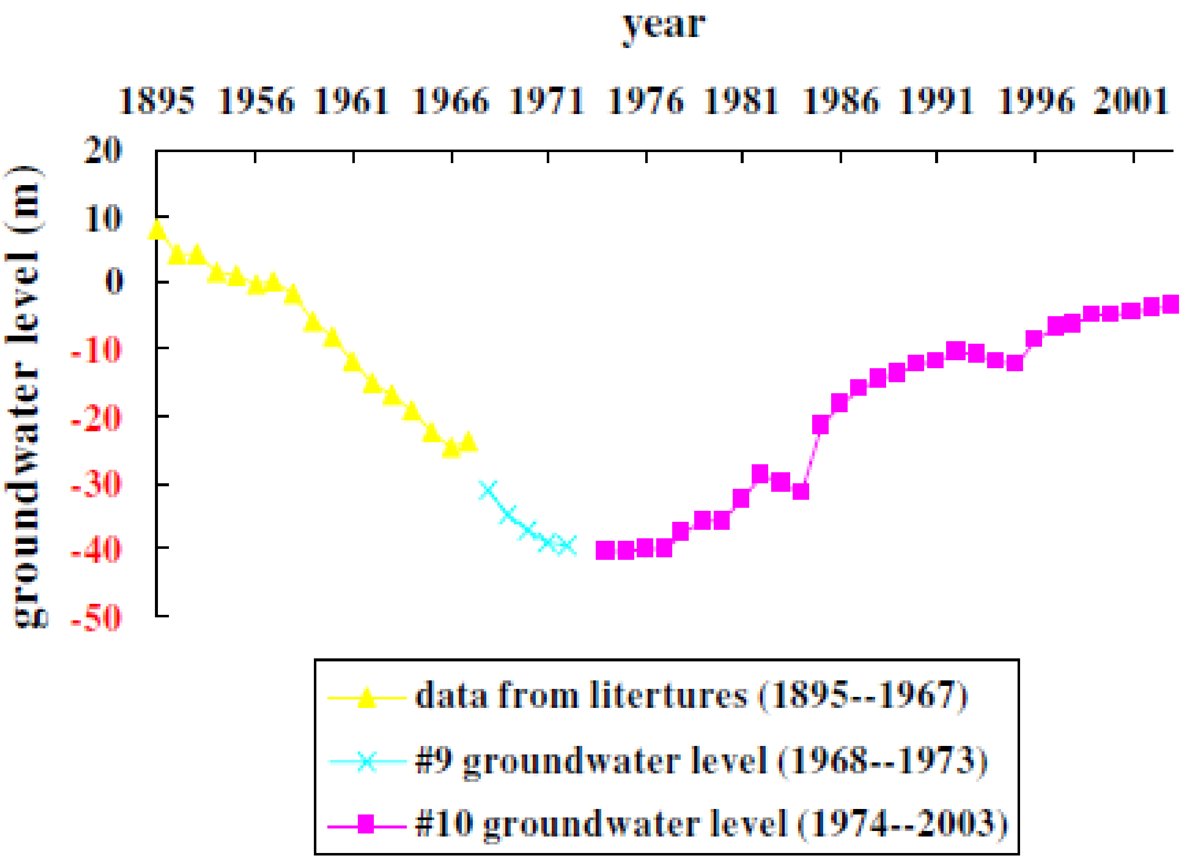


Figure E7. Groundwater levels in the Taipei Basin, 1895-2003 Source: Liu et al. (2010)

Summary of international cases of urban developments in high groundwater areas

Management strategy	Advantages	Disadvantages	Example locations	References
Constructed wetlands and detention ponds	Excavated sediment can be used as on-site fill. Opportunity for improved habitats.	Limited nutrient treatment capacity (detention ponds)	Southeast Florida, USA Chesapeake Bay Watershed, east coast, USA	Czajkowski et al. (2018); Garcia et al. (2020); Guardo et al. (1995); (Peluso & Marshall 2002; SFWMD n.d.-a); SFWMD (n.d.-b); Sukop et al. (2018)
Surface and groundwater management (*polder* system)	Water level is kept within controlled limits within the catchment	Ongoing pumping costs; subsidence; poor water quality from groundwater seepage	Amsterdam, the Netherlands	de Vries (2007); Yu et al. (2018); Yu et al. (2019)
Subsurface drainage and pumping	Groundwater levels can be managed using existing infrastructure.	High monitoring and pumping costs.	South Dunedin, New Zealand	Dunedin City Council (2018); Glassey (2018); Goldsmith and Hornblow (2016); Otago Regional Council (2019, 2020); Rekker (2012)
		Need to develop drainage system, where not existent. Need to pump and discharge drained water.	Chañar Ladeado, Argentina	Zimmermann and Riccardi (2000)
Withdrawals for secondary use	Groundwater used for potable and non-potable uses.	Requires constant monitoring	Taipei, China	Jang et al. (2019); Liu et al. (2010)

References for Appendix E

Barrell, D. J. A., Cox, S. C., Glassey, P. J., & Lyttle, B. S. 2014. 'Assessment of liquefaction hazards in the Dunedin City district'. https://www.orc.govt.nz/media/1983/technical-item-2-gns-science_cr_2014-068_dunedin-district-liquefaction.pdf

Chesapeake Stormwater Network. 2009. CSN Technical Bulletin No. 2: Stormwater Design in The Coastal Plain of The Chesapeake Bay Watershed. Chesapeake Stormwater Network

Chesapeake Stormwater Network. 2018. 'Wet Pond'. viewed. http://chesapeakestormwater.net/tag/wet-pond/

Czajkowski, J., Engel, V., Martinez, C., Mirchi, A., Watkins, D., Sukop, M. C., et al. 2018. 'Economic impacts of urban flooding in South Florida: Potential consequences of managing groundwater to prevent salt water intrusion'. *Sci Total Environ*, 621, 465-478. doi: 10.1016/j.scitotenv.2017.10.251.

Davies, C. in preparation. *Subsurface drainage for sustainable urban development*. (PhD), University of Western Australia, Perth

de Vries, J. J. 2007. 'Groundwater'. In T. E. Wong, D. A. J. Batjes & J. de Jager (Eds.), *Geology of the Netherlands* (pp. 295–315): Royal Netherlands Academy of Arts and Sciences.

Dunedin City Council. 2018. 'Significant infrastructure issues and options '. viewed 12 March 2020. https://www.dunedin.govt.nz/council/annual-and-long-term-plans/10-year-plan/section-2-strategic-overview/2.5-infrastructure-strategy/significant-infrastructure-issues-and-options

EPA. 2009. *Stormwater wet pond and wetland management guidebook*. United States Environmental Protection Agency. https://www3.epa.gov/npdes/pubs/pondmgmtguide.pdf

EuroStat. 2013. 'Archive:Coastal regions - population statistics '. viewed 12 March 2020. https://ec.europa.eu/eurostat/statistics-explained/index.php/Archive:Coastal_regions_-_population_statistics

Fordyce, E. 2014. Groundwater dynamics of a shallow coastal aquifer. University of Otago

Garcia, J., Solimeno, A., Zhang, L., Marois, D., & Mitsch, W. J. 2020. 'Constructed wetlands to solve agricultural drainage pollution in South Florida: Development of an advanced simulation tool for design optimization'. *Journal of Cleaner Production*, 120868. doi: https://doi.org/10.1016/j.jclepro.2020.120868.

Glassey, P. J. 2018. 'How future sea level rise will affect south dunedin'. *International Journal of Environmental Impacts: Management, Mitigation and Recovery*, 1(1), 40-49. doi: 10.2495/ei-v1-n1-40-49.

Goldsmith, M., & Hornblow, S. 2016. 'The Natural Hazards of South Dunedin '

Guardo, M., Fink, L., Fontaine, T. D., Newman, S., Chimney, M., Bearzotti, R., et al. 1995. 'Large-scale constructed wetlands for nutrient removal from stormwater runoff: An everglades restoration project'. *Environmental Management*, 19(6), 879-889. doi: 10.1007/BF02471939.

Jang, C.-S., Chen, C.-F., Liang, C.-P., & Chen, J.-S. 2016. 'Combining groundwater quality analysis and a numerical flow simulation for spatially establishing utilization strategies for groundwater and surface water in the Pingtung Plain'. *Journal of Hydrology*, 533, 541-556. doi: 10.1016/j.jhydrol.2015.12.023.

Jang, C.-S., Kuo, Y.-M., & Chen, S.-K. 2019. 'Assessment of shallow groundwater use for irrigating park trees in the metropolitan Taipei Basin according to variability conditions of water quality'. *Journal of Hydrology X*, 2. doi: 10.1016/j.hydroa.2018.100013.

Liu, C.-W., Chou, Y.-L., Lin, S.-T., Lin, G.-J., & Jang, C.-S. 2010. 'Management of High Groundwater Level Aquifer in the Taipei Basin'. *Water Resources Management*, 24(13), 3513-3525. doi: 10.1007/s11269-010-9617-9.

Opotiki District Council. 2019. 'Opotiki Sewerage Project FAQs'. viewed. https://www.odc.govt.nz/our-council/current-projects/sewerage-project/Pages/Opotiki-Sewerage-Project-FAQs.aspx

Otago Regional Council. 2019. 'What lies beneath Dunedin?'. viewed 10 March 2020. https://www.orc.govt.nz/managing-our-environment/natural-hazards/south-dunedin/what-lies-beneath-dunedin

Otago Regional Council. 2020. 'Water Monitoring and Alerts'. viewed 10 March 2020. https://www.orc.govt.nz/managing-our-environment/water/water-monitoring-and-alerts/dunedin/kennedy-st

Peluso, V. F., & Marshall, A. 2002. 'Best Management Practices for South Florida Urban Stormwater Management Systems.'. Florida, USA: https://www.sfwmd.gov/sites/default/files/documents/bmp_manual.pdf

Rekker, J. 2012. Sea Level Effects Modelling for South Dunedin Aquifer Dunedin, NZ: Otago Regional Council

SFWMD. n.d.-a. *Harmful Nutrients in the Everglades Now Reduced by 90%*. https://www.sfwmd.gov/sites/default/files/documents/infographic_everglades_wq.pdf

SFWMD. n.d.-b. *Infographic Rain Drain*. https://www.sfwmd.gov/sites/default/files/documents/infographic_rain_drain.pdf

Sukop, M. C., Rogers, M., Guannel, G., Infanti, J. M., & Hagemann, K. 2018. 'High temporal resolution modeling of the impact of rain, tides, and sea level rise on water table flooding in the Arch Creek basin, Miami-Dade County Florida USA'. *Sci Total Environ*, 616-617, 1668-1688. doi: 10.1016/j.scitotenv.2017.10.170.

Yu, L., Rozemeijer, J., van Breukelen, B. M., Ouboter, M., Van Der Vlugt, C., & Broers, H. P. 2018. 'Groundwater impacts on surface water quality and nutrient loads in lowland polder catchments: Monitoring the greater Amsterdam area'. *Hydrology and Earth System Sciences*, 22(1), 487-508. doi: 10.5194/hess-22-487-2018.

Yu, L., Rozemeijer, J. C., van der Velde, Y., van Breukelen, B. M., Ouboter, M., & Broers, H. P. 2019. 'Urban hydrogeology: Transport routes and mixing of water and solutes in a groundwater influenced urban lowland catchment'. *Science of the Total Environment*, 678, 288-300. doi: 10.1016/j.scitotenv.2019.04.428.

Zimmermann, E., & Riccardi, G. 2000. 'Hydrodynamic model of cells for designing systems of urban groundwater drainage'. *Hydrogeology Journal*, 8(5), 538-548. doi: 10.1007/s100400000086.

Appendix F. Summary of inputs from practitioners and researchers

Terminology

Differences in **terminology** hamper international literature review, but people are used to navigating the different terms. For example, Average Annual Maximum Groundwater Level (AAMGL) is not a clear term, and is dependent on the period of data, climate change, and will be affected by development. It was designed to protect wetlands, not development. Can we come up with a better, risk-based indicator? Further, there is a lack of clear definition of recharge (% of rainfall?). It would be beneficial to develop a Glossary of Terms, building on the Institute of Public Works Engineering Australasia (IPWEA) Guidelines, Department of Water and Environmental Regulation (DWER) publications and the like.

Risk-based site assessment

It is understood that certain areas entail higher risks than others, regarding the impact of urban developments on groundwater. Thus, consultants would typically use different approaches for different sites. For example, in high risk areas, higher levels of technical investigations are required. However, there **is no consistent, agreed framework to decide what constitutes a low, medium or high-risk site**.

Understanding the Science – Water Balance Considerations and Issues

There is a mismatch between water availability and its potential for use. Most **rainfall is concentrated in winter**, making on-site storage difficult. However, in summer, there is a shortage of water for irrigation of public open space. For this and other reasons, there is a need for greater innovation in stormwater management.

The occurrence of **clay**-rich soils across Perth affects surface-groundwater interactions, which should be taken into account. Clay may often be present at depths of 3m, and is not removed for development. During the first 300-350 mm of rain, as the clay is still relatively dry and cracked, water travels through preferential pathways, i.e. cracks of up to 65cm deep. It is not until the 300-350mm of rain threshold has been reached, that the clay swells and seals. Therefore, the role of clay cracking beneath developments should be investigated.

There is capacity to predict big floods and yearly events relatively well, **not the in-between.**

Drainage rates used in various assessments are typically based on deep water table. However, we don’t know what they are limited by in areas of high groundwater. There is a lack of understanding on whether the geofabric surrounding the subsoil drains limits the efficiency of that drainage.

There is still no clear tool to estimate **recharge**, and limited understanding of how it changes in post-development conditions. Future research should investigate rates of recharge for various land uses, landforms, vegetation covers, soils and geology. Further, more research is needed for the understanding and representation of mounding under different conditions.

There is a lack of clarity on whether **soil moisture** should be used as a good predictor of runoff coefficient.

Model structure and parameters

There is a lack of **consistency in methods** used. Small-medium size consultants use older methods, while large consultants use pretty consistent methods, following ARR 2016.

In general, the uncertainty in soil parameters, recharge rates, and model "correctness" are not well understood, meaning that the **margins of error** to be expected around model results are also poorly known.

There is lack of clear, consistent agreement on **clearance to groundwater levels** between Local Government authorities. Specific levels and clearances within IPWEA guidelines should be subject to ongoing discussion, as there has been indication that the clearances recommended for gardens and playing fields may not be sufficient and may result in waterlogging. Other confounding factors may be at play with specific developments also.

Heterogeneities in soil are an important issue. Often, spatial heterogeneities occur locally, to the point that they cannot be captured in the models. For example, care should be taken to delineate areas of clay lensing or limestone. Potentially, models may need to be run separately for different areas of the site where such heterogeneity exists.

There is a need to better know and describe the "**boundary" conditions** that may be applying at smaller scales of investigations and developments.

Technical evaluation of development planning should be undertaken early in the planning process in order to account for cumulative impacts. This could potentially be done at the District Water Management Plan or earlier. It could also be used to determine what parameters are most appropriate where.

Monitoring

Post-development monitoring often doesn't start until the last phase of development is completed, meaning it can be 15 years between initiation of development and when monitoring is installed. DWER's guidelines for preparing Urban Water Management Plans (UWMPs) indicate that monitoring should extend for at least three years after the last stage of construction of the subdivision. However, this applies to the whole development, not each cell. As many projects are at mid-development stage, they can be 10 years out of monitoring. Although some early monitoring may occur, it is usually for quality, not quantity. This gap in monitoring times represents a lost opportunity for adaptive management when problems do arise. Further, there is currently a lack of well monitored demonstration sites. Post-development monitoring should inform how subsoil drainage systems perform over time, while post-development models could be used to better understand what really happened. Thus, there is a need for assessment of performance of existing designs. It is advised that longer term monitoring and research of sub-soil drainage systems are investigated in several different environments. The Groundwater Steering Group could do demonstration projects to provide more evidence for how well the IPWEA guidance works.

Construction/Development Practices

Increased attention to design and management of groundwater drainage presents win-win situations for homeowners, developers and the environment.

Currently, designs tend to be very conservative and thus, unnecessarily increase the use of fill. This results in:

- Costs to developers that are passed onto homebuyers; therefore increased costs of housing;
- Clearing of sand environments from which fill is sourced;
- Carbon and transportation impacts;
- Larger changes in the elevation and relief of the built environment, including some "Frankenstein" landscapes, with unknown impacts on sensitive environments, hydroperiod etc.

Alternatively, insufficiently conservative / poor design is resulting in groundwater flooding and nutrient management impacts. This can result in:

- Liability to Local Governments for infrastructure repairs (~ $1 million for road replacement in one example);
- Untested liability of Local Governments for damages to private property;
- Exposure to increased regional and local flood hazards;
- Loss of amenity (soggy backyards, mosquito breeding etc);
- Damage to private property (unclear how insurers and insurance industry is looking at this problem).

One estimate indicated the payoff of additional **testing and modelling** upfront is likely to **be 10:1** or better in terms of reduced fill costs (for developers). Therefore, improved practice in this area represents a great opportunity for WA. However, where minimisation of fill is a goal, it remains unknown whether modelling can ever provide a sufficiently precise prediction to avoid residual risk. It is therefore necessary to also achieve further innovation in construction methods/materials.

It is difficult to make consistent **fill blends** at subdivision scale. On one reported occasion, a whole street went "soggy", resulting in direct connection of properties to roadway drainage (although the Local Government prefers indirect connection).

Lack of **maintenance** is a big issue; biofilters and living stream are good features, but need better expertise to maintain, otherwise there are high costs. Raingardens are difficult because vegetation dies in summer. Other issues include, for example, infiltration going wrong on biofilters; not draining as quickly as they should. There is a need to better understand how biofilters perform; differences between rising and falling limbs and when there is groundwater contribution or no groundwater (groundwater anecdotally reduces performance by about 30%).

Question to be further investigated include:

- What is the loss of porosity in silty soils?
- What is the K value of the compacted fill?

Soakwells

The efficiency of soakwells is not well modelled, as typically ideal drains are assumed. Assumptions about locations are made in models that can influence mounding - handled by assuming they will be in rear of house (conservative approach).

Lots less than 350 square metres can't get soakwells on-site, especially not anything big enough, so they need direct/indirect connection. The Local Government can't control where soakwells go, as it's up to the owner and builder. However, when things go wrong, owners come to the Local Government and ask for the problem to get fixed (this links to governance and chain of responsibility issues).

There are difficulties of using in-situ sand; if low permeability sand is on top, we will have soggy backyards even though high K value sand below.

There is a lack of clarity on how do silting and acid sulphate soils affect soakwell infiltration 10 years down the line.

Consistency between environmental design, civil design, and as built is a challenge. This challenge may need to be confronted if optimising design requires ensuring e.g. soakwells at front of lots, use of high quality soakwells, etc.

Governance

It is recognised that land development has cumulative environmental impacts (on flooding, water quality and GDEs), although these are currently not adequately captured or managed during early stages of the planning process. Furthermore, UWMPs are often only submitted for approvals at later stages of the planning process when, in some cases, it is already too late to incorporate considerations for water balance and implement adequate water management measures. **Late introduction of detailed hydrological assessments** within the planning process is particularly problematic for cumulative impact mitigation. Thus, water balance considerations need to come earlier in the approvals processes.

Different **government agencies have different mandates and responsibilities**, which hinder the water planning processes. The purpose of the Western Australian Planning Commission (WAPC), which operates with the support of the Department of Planning, Lands and Heritage (DPLH), is to undertake and regulate land use planning and development. Contrastingly, the scope of the Department of Water and Environmental Regulation (DWER) is to manage and regulate the state's environment and water resources. Moreover, there is a disconnect between local and district level planning. On the one hand, local water management strategies (LWMSs) are approved, on the advice of the DWER and input where required from the Water Corporation, by the WAPC, which operates with the support of the DPLH. On the other hand, UWMPs are approved by the Local Government authorities, i.e. cities, towns or shires. Therefore, there is a need to consolidate communication and advice between Local Governments, DWER, the Department of Biodiversity, Conservation and Attractions (DBCA) and other authorities with statutory oversight of cumulative impacts. A suggestion to harmonise advice/approvals is to create working groups between councils/agencies. This could be in the form of a centralised technical review/advice hub made up of specialised personnel, which could be situated within Regional Councils.

There are **breaks in the chain of responsibility** within the planning, design and construction process. These can be exacerbated by separation of responsibilities within State and Local Government departments, and a shift of responsibility between private and public entities. Once assets have been handed over to the Local Government, it is unclear who is responsible for what.

Although council rates do not include fees for managing groundwater in private areas, these can end up being a large expense for Local Governments. It is for this reason that Local Governments are very conservative, risk-averse, which means their engineers also become so – potentially leading to unnecessarily high construction costs. In some cases, councils even ask for parameters that aren't appropriate, because of their risk-aversion, or because they lack adequate expertise to evaluate models. Often, **local governments have limited financial and skill capacity** to review and approve technical hydrological /hydrogeological /engineering works.

The legal framework for **drainage** is fragmented and incomplete, as drainage is not subject to a separate act. It is touched upon by the Local Government Act and by Common Law. Issues such as infrastructure on private land, which needs to be maintained to achieve public good (e.g. subsoil drainage systems), fall into a legal ambiguity.

Appendix G. Glossary of Terms

Average Annual Maximum Groundwater Level (AAMGL) - The long-term peak groundwater behaviour at a site under pre-development land conditions

Annual exceedance probability (% AEP) - The probability that a given event will occur or be exceeded in any year

Aquifer - A geological formation or group of formations capable of receiving, storing and transmitting significant quantities of water

Baseflow – The portion of streamflow delayed high subsurface flow

Biofilter A stormwater management device that consists of an excavated basin or trench that is filled with porous media and planted with vegetation

Bore - A narrow, lined hole drilled to withdraw or monitor groundwater

Capacity building program - A holistic approach to knowledge building and transfer, which fosters skill development, competency, innovation and confidence. It is also a means to facilitate network building, linkages and training for continuous improvement

Capillary fringe - Part of the unsaturated zone, where soil voids are filled (or almost filled) with water due to capillary rise

Catchment - A topographically defined area draining surface water to a single outlet point

Channel - The bed and banks of a stream or constructed surface water drain that carries all flows except floods

Clay (soils) - A fine-grained mineral soil consisting of particles less than 0.002 mm in equivalent diameter

Compaction - Any process whereby the density of soils is increased. This process results in lower permeability and poorer soil aeration

Controlled groundwater system - A groundwater system that is subject to control or management through the provision of drainage infrastructure

Controlled groundwater level (CGL) - The invert level of groundwater controlling infrastructure

Drainage water - Consists of stormwater runoff and/or high groundwater that has been intercepted by drains

Ecological values: Particular values or uses of the environment that are important for a healthy ecosystem or for public benefit, welfare, safety or health and economic activities, and which require protection from the effects of pollution, waste discharges and deposits and from the effects of altered water regimes

Evaporation – The primary pathway that water moves from the liquid state into the water cycle as atmospheric water vapour

Groundwater - Water in the soil voids of the saturated zone

Groundwater-dependent ecosystems (GDEs) - Ecosystems that require access to groundwater to meet all or some of their water requirements so as to maintain the communities of plants and animals, ecological processes they support, and ecosystem services they provide

Groundwater level - The non-static top of the saturated zone (can include locally perched groundwater)

Hydraulic conductivity - A measure of the ease of flow through a pore space or fractures. Hydraulic conductivity has units with dimensions of length per time (e.g. m/s, m/min, or m/d)

Hydrologic regime - A description of the variation of flow rate or water level over time

Hydrological cycle - The continual cycle of water between the land, the ocean and the atmosphere

Hydrology - The science of the behaviour of water in the atmosphere, on the surface of the earth and within the soil and underlying rocks. This includes the relationship between rainfall, runoff, infiltration and evaporation

Impermeable or impervious surface - The part of the catchment surfaced with materials, either natural or constructed, which prevent or limit the rate of infiltration of stormwater into the underlying soil and groundwater and subsequently increases stormwater runoff flows

Infiltration - The movement of water from the surface to the subsoil and at times, ultimately to the underlying aquifer

Infiltration system - A drainage facility designed to use the hydrologic process of stormwater runoff soaking into the ground, commonly referred to as percolation. Examples include infiltration basins and trenches, soakwells and pervious paving

Interflow – The lateral movement of water in the unsaturated zone. As water accumulates in the subsurface, saturation may occur and interflow may exfiltrate, becoming overland flow

Managed aquifer recharge (MAR) - The controlled infiltration or injection of water into an aquifer. The water can be withdrawn at a later date, left in the aquifer for environmental benefits, or used as a barrier to prevent saltwater or other contaminants from entering the aquifer

Monitoring - The collection of data by various methods for the purpose of understanding natural systems and features, evaluating the impacts of development proposals on such systems, and assessing the performance of mitigation measures

Overland flow: The component of rainfall (excess) that is not removed by infiltration or use and discharges down-gradient as surface flow

Perched groundwater - Groundwater that occurs above the regional water table, as a distinct saturated zone embedded within the unsaturated zone due to the presence of an aquiclude or aquitard

Phreatic surface - The non-static top of the saturated zone in a controlled groundwater system

50% AEP phreatic surface - The phreatic surface that will be exceeded in 50% of years (50% chance each year).

20% AEP phreatic surface - The phreatic surface that will be exceeded in 20% of years (20% chance each year).

Receiving water bodies: Include waterways, wetlands, coastal marine areas and high groundwater aquifers

Recharge - Water infiltrating to replenish an aquifer (note there are terms of NET recharge (i.e. recharge - evaporation or transpiration from the water table) and GROSS recharge (i.e. event-scale recharge))

Retention/retain - Retention is defined as the process of preventing rainfall runoff from being discharged into receiving water bodies by holding it in a storage area. The water may then infiltrate into the soil or other media, evaporate or be removed by evapotranspiration of vegetation

Risk - The chances of something happening that will have an impact on objectives. It is measured in terms of consequences and likelihood

Risk assessment - The process of risk analysis and risk evaluation

Runoff - Water that flows over the surface of a catchment area, including streams

Sand - A soil consisting of particles between 0.02 and 2.0 mm in equivalent diameter. Fine sand is defined as particles between 0.02 and 0.2 mm, and coarse sand as those between 0.2 and 2.0 mm

Saturated zone - The part of the soil profile where voids are completely filled with water

Seasonally perched groundwater - Perched groundwater that is seasonally connected to the underlying water table

Silt: A soil consisting of particles between 0.002 and 0.02 mm in equivalent diameter

Soil amendment - Involves adding an agent to the soil to improve its structure, porosity, water holding capacity and/or nutrient recycling capacity

Soil permeability - The ease with which gases, liquids or plant roots penetrate or pass through a layer of soil

Soil stabilisation - The use of measures or materials to prevent the movement of soil when loads are applied to the soil

Source controls - Non-structural or structural best management practices designed to minimise the generation of excessive stormwater runoff and/or pollution of stormwater at or near the source and protect receiving environments

Stormwater - Water flowing over ground surfaces and in natural streams and drains, as a direct result of rainfall over a catchment. Stormwater consists of rainfall runoff and any material (soluble or insoluble) mobilised in its path of flow

Stormwater quality - The chemical, physical and biological characteristics of stormwater

Stormwater quantity - The volume characteristics of stormwater

Subsurface drain - A drain designed to intercept subsoil water and thereby limit the groundwater level

Superficial (unconfined) aquifer - An aquifer containing water with no upper non-porous layer to limit its volume or to exert pressure. The upper surface of the groundwater within the aquifer is called the water table

Surface water - Water flowing or held in waterways or wetlands on the surface of the landscape

Swale - A drainage interception and conveyance system with relatively gentle side slopes and high flow depths

Transpiration – is the process of water movement through a plant from absorption primarily through the roots to evaporation from aerial parts

Unsaturated zone - The part of the soil profile where voids are only partially filled with water.

Urban - Land used for residential, rural-residential, commercial or industrial development

Vegetated swale - A swale with vegetation covering the side slopes and base. Vegetation can range from grass to native sedges and shrubs, depending on hydraulic and landscape requirements

Water bodies - Waterways, wetlands, coastal marine areas and high groundwater aquifers

Watercourses - A river, stream or creek in which water flows in a natural channel, whether permanently or intermittently

Water dependent ecosystems - Those parts of the environment, the species composition and natural ecological processes of which are determined by the permanent or temporary presence of water resources, including flowing or standing water and water within groundwater aquifers

Water sensitive urban design (WSUD): A design philosophy that provides a framework for managing water-related issues in urban areas. WSUD principles include incorporating water resource management issues early in the land use planning process. WSUD can be applied at the lot, street, neighbourhood, catchment and regional scale.

Water table - The non-static top of the saturated zone (generally does not include locally perched groundwater)

Waterways - All seasonal, intermittent or permanent streams, creeks, rivers, estuaries, coastal lagoons, inlets and harbours

Wetlands - Areas of seasonally, intermittently or permanently waterlogged or inundated land, whether natural or otherwise, including lakes, sumplands, playas, damplands, floodplains, barlkarras, palusplains, paluslopes, palusmonts or tidal flats

CRC REPORT RECOMMENDATIONS

IRP3: Enabling water sensitive urban development: planning and governance opportunities for Perth.

1. Undertake corridor level water planning as part of state government's integrated strategic planning and urban development program
2. Mandate the assessment of non-potable water supplies for public open space in the new State Planning Policy for water, and elevate status of Better urban water management to an operational policy
3. Rename urban zone for land with shallow groundwater (for example, 'Urban – shallow groundwater') that requires appropriate environmental management of shallow groundwater as part of the land's future urban development
4. Incorporate building material palette in Design WA project through the Residential Design Codes (R-Codes) Volume 1 reforms which are universally applicable through local planning schemes
5. Determine the cost of providing non-potable water to public open space at the Perth metropolitan scale and apply it to all rateable properties as a water resources charge
6. Mandate integrated water management standards or targets for urban development on the Swan Coastal Plain in local planning schemes, supported by Better urban water management as an operational policy
7. Have an agency or servicing authority complete regional water planning and resource assessments that specify service outcomes for water supply (potable and non-potable), surface and groundwater use and management (including protection of environmental assets, flooding, inundation and water quality), and wastewater management
8. Have servicing authority plan water system services at a corridor scale and develop business cases for regional and sub-catchment servicing schemes (including infrastructure that local government will own and operate)
9. Ensure local structure plans establish land uses and integrate infrastructure, as identified in servicing schemes, including funding and ownership arrangements
10. Consider local governments' role as a determining authority for local structure plans and local water management strategies
11. Require collaborative project planning, assessment and infrastructure delivery as part of corridor planning and structure planning processes.

IRP3: Brabham Action Learning Partnership: Case report

1. Establish a working group to continue a collaborative approach to the planning and approval of Brabham
2. Address outstanding questions on the financing, operation and governance of the subsoil drainage harvesting scheme
3. Explore barriers and opportunities for alternative built form and urban form
4. Engage in ongoing communication and advocacy for the uptake of innovative, fit-for-purpose solutions

IRP5: Expert Panel on urban developments impacted by high groundwater - Final report containing initial guidance and recommendations for future research and other work

Key Findings

1. Changes to the status quo can bring benefits - adoption of best practices or changes in the development methods could present a win-win-win opportunity for the public, the environment, and for land development interests.
2. There is a need for better technical guidance on and understanding of the urban water balance
3. Earlier decision making in the planning and approval processes can mitigate cumulative adverse impacts
4. Different approaches are required for different levels of groundwater risk
5. Technical demands on Local Governments are significant
6. Lack of clarity around governance responsibilities can present barriers to good technical results
7. Several other barriers need to be overcome to satisfy the appetite for greater innovation
8. Better use can be made of existing and future monitoring information -

Key Recommendations for future research and other work

Research and/or other work should be undertaken to:

1. Improve understanding of recharge dynamics of the pre- and post-development landscape at a range of scales
2. Improve the understanding of the risks associated with common modelling assumptions,
3. Develop tools to facilitate the technical assessment of proposals by Local Governments
4. Proceed towards the creation and evaluation of demonstration projects on topics including:
    a. Alternative construction methodologies and urban and built forms appropriate to high groundwater environments,
    b. The performance of a variety of precinct, sub-division, and on-lot stormwater management strategies,
    c. The feasibility of rear-of-lot directly connected drainage of the local groundwater mound; and
    d. Landscaping approaches that are compatible with high groundwater in lot rears and in public open spaces.
5. Expand on the work of this project to cooperatively develop a comprehensive technical guidance note, supported by the urban development industry and regulators, for planning and designing urban developments in high groundwater areas.
6. explore the policy, regulatory and governance issues and options identified in this report, including greater legislative clarity, to reduce or remove barriers to the implementation of otherwise sensible technical solutions.