CRC for
Water Sensitive Cities

Integrated Research Project 5 Knowledge based water sensitive solutions for development in high groundwater environments

Stage 1 Report

Prepared by GHD, Water Technology and the University of Western Australia

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Stage 1 Report –2018

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1 Introduction

1.1 Purpose and scope

GHD, Water Technology and the University of Western Australia were engaged by the CRC for Water Sensitive Cities (CRCWSC) to undertake Stage 1 of Integrated Research Project 5 (IRP5) - *Knowledge-based water sensitive city solutions for groundwater impacted developments*. IRP5 aims to better understand the impact of urban development in groundwater impacted environments and will generate water sensitive solutions for areas with high groundwater tables. The outputs from the project will include guidelines and innovative solutions that achieve effective water sensitive outcomes for groundwater impacted developments. The project will focus on a research case study located at Brabham, in the Swan Region of Western Australia, jointly with WA Dept of Communities.

1.2 Study Objectives and Context within the IRP5 Project

Stage 1 of IRP5 is a Scoping Study, which involves collating existing knowledge and the coordination of a Research Action Plan for Stage 2. The objectives of Stage 1 are to:

- Collate and critically evaluate the current state of knowledge locally (WA/Australia) and globally in the design and implementation of urban (residential) development and water management approaches in areas with high and variable groundwater tables, focused on addressing priorities directed by the Project Steering Committee (PSC).
- Identify contested or unknown design and implementation parameters and methodologies for such developments and urban water management systems that could be further investigated (at full scale) in the follow-up project phase (Stage 2).
- Investigate alternative building/construction and land development methods and their performance in high-groundwater environments from a national and international perspective.
- Develop an action and research plan to address key knowledge gaps, with a focus on applications to inform water sensitive development at the Brabham research case study site.

1.3 Definitions

This project uses the following definitions:

High groundwater: When the water table is within 4 m of the natural ground surface. Includes regional unconfined aquifers and local seasonally (perched) water tables. Also referred to as “shallow groundwater” or “near-surface groundwater” throughout this report.

Superficial aquifer: is the aquifer nearest the surface, having no overlying confining layer.

The state of knowledge of the topics investigated by this report falls on a spectrum ranging from unknown to known. This report assesses the topics’ position on the spectrum by presenting the available information, classifying the topic into one of four categories:

Evidenced: That which is evidenced through scientific methods with negligible disagreement amongst experts.

Agreed: That which is generally agreed amongst experts or practitioners, with little deviation. This includes practices that are agreed, but lack a scientific basis.

Contested or uncertain: That which is contested between experts or practitioners, or subject to a wide range of understanding.

Unknown: That which is largely or completely unknown.

1.4 Report style

1.4.1 State-of-knowledge summary

Summaries of the state of knowledge are provided at key junctures in this report using the following style.

Evidenced	• Knowledge item
Agreed	• Knowledge item
Contested	• Knowledge item
Unknown	• Knowledge item

1.4.2 Interview quotations

Quotations from interviewees are provided either in paragraph or stylized as follows.

Unsaturated zones are not at all well known

1.5 Methodology

The methodology adopted for this project is broadly to:

- Evaluate current academic literature on the above topics (noting that a literature review was available from the previous CRCWSC Research Project B2.4)
- Investigate gray literature and industry expertise and sources locally and globally on the topics described in the Objectives section (Chapter 1.2).
- Summarise and critically evaluate the current literature on the aforementioned topics, including areas:
  - o where evidence is available and appears to be sound;
  - o where there is generally shared agreement and alignment in professional judgement; or

    - where there is disagreement or uncertainty e.g. quantify the range in criteria or parameters used in urban hydrology or hydraulic modelling.

- Conduct structured interviews with key stakeholders and experts locally and globally (identified in cooperation with the Project Steering Committee, PSC) and compare the results of these interviews with findings from the literature review.

- Identify key design and implementation parameters that are contested or unknown and could be further investigated in Stage 2.

- Conduct a joint workshop with key stakeholders to discuss, evaluate and consolidate the identified key design and implementation parameters and methodologies that need further investigation through practical research activities.

- Integrate and summarise findings from the above key activities in a "State-of-knowledge" document as a final report from the study, which includes:

    - Preliminary best practice recommendations, supported by robust evidence where available, that industry can use to guide water sensitive development in high groundwater environments, with a focus on solutions that can be applied or trialled at Brabham;

    - Recommendations in respect to what is required to change practice and achieve more water sensitive developments in high groundwater environments; and

    - An outline of key knowledge gaps that need to be addressed to improve industry capacity to achieve water sensitive developments in high groundwater environments, with a focus on those gaps that need to be addressed to achieve an exemplar water sensitive development at Brabham.

- Facilitate/coordinate the development of a Research Plan for Stage 2 that is focused on the Brabham case study, with input from the Project Steering Committee, UWA, Dept of Community and the Dept of Water and Environmental Regulation.

1.6 Sources of Information

1.6.1 Written sources

Written sources include International and National industry guidelines, policies, standards, and technical reports. Technical reports were typically Local Water Management Strategies and Urban Water Management Plans developed under the Western Australian Better Urban Water Management framework (Western Australian Planning Commission, 2008). Information sources are cited throughout the document and listed in Chapter 7.

1.6.2 Expert Interviews

Practitioner and stakeholder interviews were undertaken to capture knowledge and experience from practitioners familiar with the challenges posed by urban development in high groundwater environments. The practitioners were selected by the PSC based on the following criteria:

- Balance of urban development, government, water utility and research personnel, with an emphasis on those with the requisite technical knowledge to answer the interview questions.

- Geographic spread, both nationally and internationally.

- One from each organisation.

- Availability and willingness to participate.

In total, twenty practitioners and stakeholders were interviewed. The list of interviewees, interview questions and answers are provided in Appendix 1. The information obtained from the interviews is cited throughout the document, using named sources where consent was given, or anonymous sources where it was not.

2 Background and setting

2.1 Pre-development environment

The pre-development environment as defined in this chapter refers to the environmental setting immediately prior to urban development, whether this is an undisturbed natural environment, or a disturbed environment such as an area of agricultural land use.

Understanding the pre-development environment is essential to undertaking urban development in order to set a water balance and quality baseline.

2.1.1 Water balance

The water balance of a pre-development environment is a product of the relationship between rainfall, runoff, infiltration and evaporation characteristics and the unique environmental characteristics of a site and its catchment (soils, vegetation and topography). Water also enters and leaves the shallow aquifer and the deep (confined) aquifer. The conceptual water balance model illustrated in Figure 1 is evidenced from numerous studies.

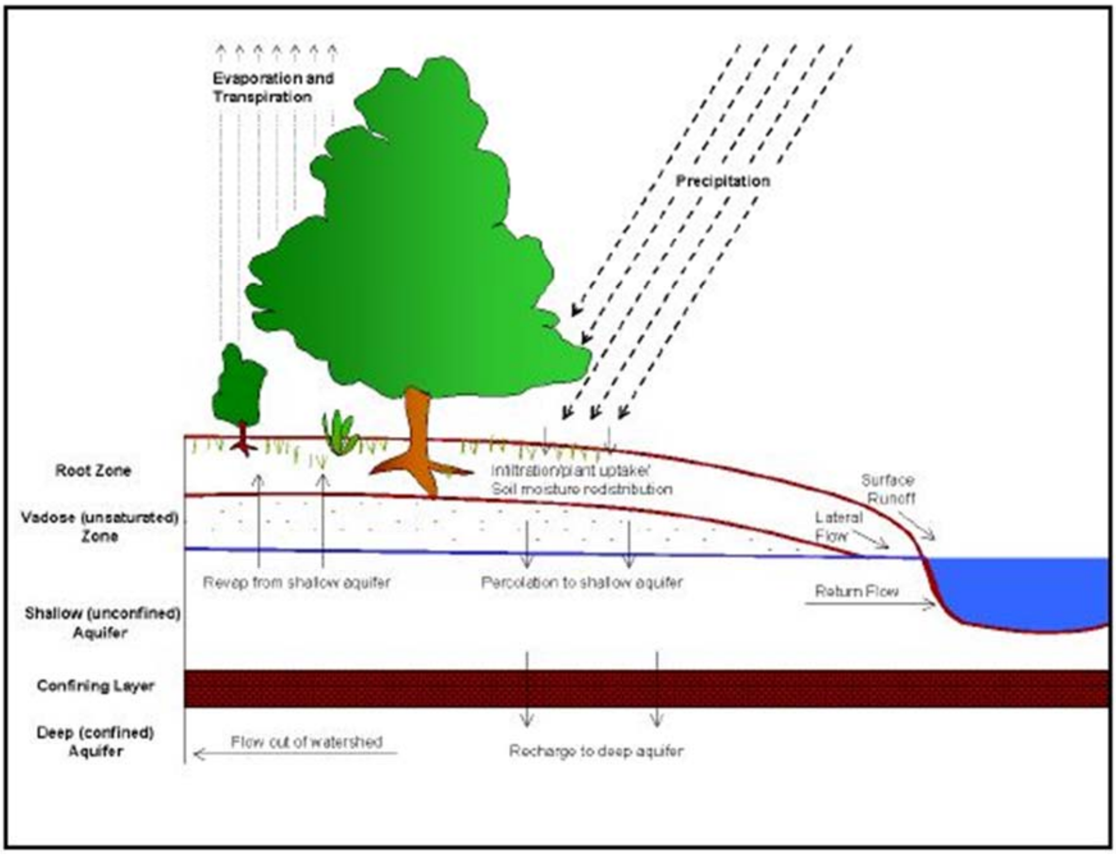

Figure 1 Pre-development water balance

2.1.1.1 Precipitation

Precipitation depths, intensities, seasonality, and temporal patterns are well understood in Australia through a network of public and private rainfall gauging stations and detailed analyses by the Bureau of Meteorology.

Methods for predicting the impacts of climate change on rainfall intensity are provided by Australian Rainfall and Runoff (Ball, et al., 2016), whilst seasonal and annual changes in rainfall depth due to climate change are also provided by the CSIRO and Bureau of Meteorology (Clarke, et al., 2011).

2.1.1.2 Interception

Interception of precipitation by leaves, branches and groundcovers is a loss from system. Characteristics such as trees/ha, branch angle, the uniformity or lack of uniformity in crown height, the nature and thickness of the bark layer, leaf shape and inclination, and leaf area index will all influence interception. External factors such as rainfall intensity and wind strength also influence interception rates. Whilst it is difficult to draw general conclusions about interception losses by particular forest types, carefully conducted event-based studies can quantify the influence of a number of the variables (Crockford & Richardson, 2000). High groundwater levels do not directly influence interception losses. Interception losses are therefore categorised as agreed.

Given that interception rates for eucalypt species have been measured at up to 11% of the annual rainfall depth (Crockford & Richardson, 1990) and 30% per annum for pine plantations (Silberstein, et al., 2012), they can be a significant component of a site's water balance.

2.1.1.3 Surface water runoff

Surface water runoff is a function of precipitation (spatial and temporal), topography, surface roughness, infiltration and, to a lesser extent, interception. Considerable research has been undertaken to understand catchment runoff rates and volumes over broad temporal and spatial scales. Different interpretations of variables by practitioners invariably lead to a range of runoff estimates, however the processes and parameters for a given catchment are generally agreed with little deviation, where groundwater levels are low.

Where groundwater levels are at or near the surface, runoff rates and volumes are not well predicted - largely due to significant variations in infiltration loss parameterisation. This is particularly the case for event based hydrology rather than seasonal or long term hydrology, where rainfall intensity exceeds the saturated hydraulic conductivity of the soil. Surface water runoff can also be generated where groundwater rises above the ground surface, or where groundwater is intercepted by a waterway or drain.

2.1.1.4 Evapotranspiration

Evapotranspiration (ET) includes canopy evaporation, vegetation transpiration, ground surface evaporation, and soil evaporation from both the saturated and unsaturated zones. Canopy evaporation, vegetation transpiration, and surface water evaporation are all well researched. Within the root zone, evaporation and plant uptake rates are also well researched. However, research associated with evaporation rates in high groundwater environments is limited. Recharge rates can be used as an indicator of ET rates, and are discussed in Chapter 2.1.1.6.

Areas with sparse vegetation, an abundance of bare soil, shallow groundwater and dry climatic conditions are prone to substantial groundwater evaporation, particularly during long dry seasons (Balugani, et al., 2017) Conversely, in a wet climate, soil water plays a negligible role in evapotranspiration at depths greater than 0.75m (Wilson, et al., 2001).

In the presence of trees, Carter et al. (2010) report that a plantation of trees can be more effective than a pump in maintaining a deep water table and thereby controlling waterlogging and associated salinity. Farrington et. al. (1989) identified a positive correlation between increasing groundwater depth and evapotranspiration rates amongst native vegetation, however the correlation was weak, of moderate confidence (R^2=0.6), and only applied to groundwater depths between 5m and 12m. Conversely, Barron et. al. (2012) found that evapotranspiration rates are lower with a diminishing access to groundwater. It is therefore concluded that evapotranspiration fluxes in high groundwater environments are largely unknown.

2.1.1.5 *Lateral flow*

Lateral flow within the root and vadose zones is a function of the continuity of the soil and perching horizons, storage capacity of the soil, soil permeability, and slope of the soil and perching horizons. Literature for simple homogeneous systems is common, however the variability of these factors in natural environments results in uncertainty in real world applications.

Soil moisture content thresholds to initiate flow, recharge reaching the water table and their rates, and the need to overcome water storage thresholds for lateral flow initiation in the landscape become critical. There is common agreement in the scientific community that this is a knowledge gap which has significant need for improved parameter estimation in existing models. Lateral flow is therefore considered a contested topic. However given that lateral flows typically represent only a small proportion of the water balance, the importance of understanding this science is low.

Unsaturated zones are not at all well known

2.1.1.6 *Recharge*

After losses to ET, runoff and lateral flow, recharge rates of remaining soil water are determined by:

- Soil characteristics including ease of entry, storage capacity, and transmission rate through the soil;
- Vegetation type, particularly root characteristics; and
- Antecedent moisture conditions.

Pre-development infiltration rates are estimated by practitioners using a variety of methods. Shukla (2003) analysed ten infiltration models including Green-Ampt and Horton's models, using double-ring infiltrometer tests, and reported that Horton's model gave the best results for most land use conditions.

In areas of very high groundwater, where the vadose zone is absent and soil moisture is high or saturated, surface water runoff rates are higher.

In the Perth region, in locations of Bassendean soil where groundwater is within 4m of the surface, recharge rates are estimated to be between -35% to +32% of annual rainfall for pine plantations, between +6% to +39% of annual rainfall for banksia forests, and +45% of annual rainfall for pasture (Xu, et al., 2009).

Understanding and quantifying pre-development infiltration rates is essential for urban development, where practitioners seek to maintain pre-development hydrology. If infiltration rates are under-estimated, practitioners may overdesign post-development infiltration measures, increasing groundwater levels and reducing surface water runoff. Conversely, the over-estimation of pre-development infiltration rates may under-design post-development infiltration measures, leading to excess post-development runoff.

2.1.1.7 *Groundwater flow*

The theory to describe the movement of water in a shallow unconfined aquifer and its interaction with a surface water body (stream, wetland, lakes and drains) is well understood and agreed (see (Pinder & Celia, 2006)). The theoretical hillslope shown in Figure 2 presents lines of equal hydraulic head (fluid potential) that drive the groundwater flow in three different areas: the upland (F), mid-slope (E) and near-stream (D) riparian zones.

The water table elevation corresponds to the value of the fluid potential (i.e. the contour value) at the point where it intersects the water table (shows as horizontal dashed lines in A,B,C). The flow field at each landscape region (denoted by F,E,D) in Figure 2 shows downward movement in region F, horizontal flow in region E (where potential lines are vertical), and finally upward flow in region D (where potential increases with depth) indicating the discharge point into a stream or above ground (spring). This theoretical flow dynamic corresponds to homogenous-isotropic media, under a given recharge rate to the water table via the unsaturated zone (vertical arrows in Figure 2) and in absence of vegetation and/or pumping extractions.

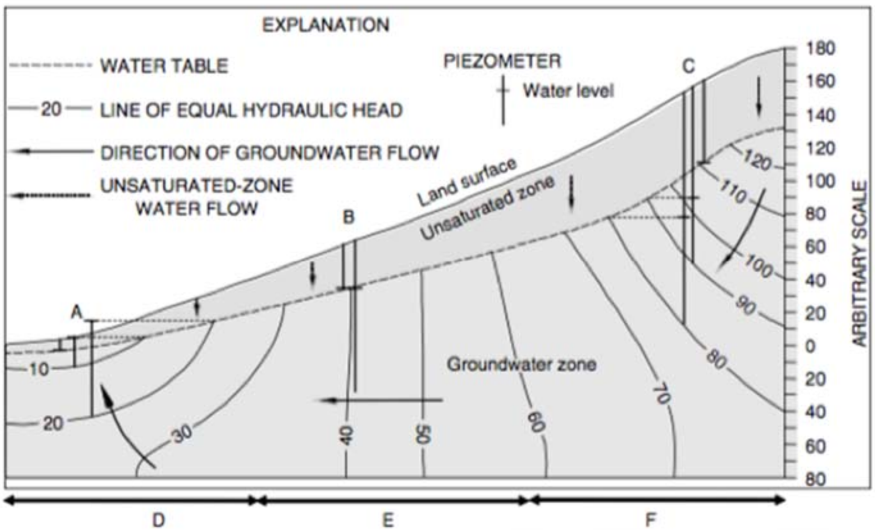

Figure 2 Superficial groundwater flow in the near-stream environment

Numerical groundwater models currently available reproduce these dynamics and it can be concluded that this is not an area of contested knowledge. Models are used for surface-groundwater interactions (Fleckenstein, et al., 2010), assessing the impact of climate change on these interactions (Saha, et al., 2017), and the assessment of management strategies in near stream zones for vegetation health (Doody, et al., 2009) and pollutant dynamics. However, the difficulties in transferring understanding of these processes across varying spatial-temporal scales needs to be understood (Fleckenstein, et al., 2010).

Predicting water table levels along the landscape in natural systems also presents difficulties due to processes governing water flow and pathways in the unsaturated zone, which ultimately affect recharge to the water table. This has been the focus of research on hillslope hydrology over the past three decades and it relates to the questions: How does the water from a rainfall, or irrigation event reach the stream, drains, and subsoil drains over the course of an event? And how does the water table develop in space and time affecting groundwater discharge to streams?

Difficulties in practical applications are often associated with assumptions of unsaturated zone hydrology and soil physics as well as a lack of information to properly characterize the subsurface environment and most importantly the depth of the impeding or impervious layer along the landscape. A more realistic view of water table elevation in Figure 2 requires an understanding of how recharge rates change along different zones of the landscape.

Lateral flow in the subsurface occurs mainly as shallow throughflow saturated path (upper soil layers) and saturated flow from the unconfined aquifer. Both water sources have been identified to be dominant on runoff and pollutant generation pathways from forested and agricultural landscapes (Vidon & Hill, 2004). Significant research in headwater catchments has demonstrated the linkage between the hydrology of near stream zones and its upland landscape and their role on the catchment water balance and hydrochemistry. The size of the upland aquifer (unconfined) has been shown to impact on the magnitude and seasonality of subsurface flow inputs to lowland areas (Devito & Hill, 1998); whilst the depth and permeability of saturated sediments overlaying a confining layer influences flow paths, water residence times and water-vegetation interactions (Hill A.L., 1996)

(Correll, et al., 1997). Topography plays an important role in local infiltration and recharge processes impacting on the hydraulic gradient of the water table towards lowland and near stream areas (Devito, et al., 2000).

Hydrological connectivity, defined as the ability to transfer water from one part of a landscape to another (Ocampo, et al., 2006) (Bracken & Croke, 2007), has proven to allow the integration of several complex processes into patterns that reflect the transfer of a mass of water and solutes across different portions of the landscape. Shallow subsurface flow connectivity has been shown to impact on dissolved organic carbon (McGlynn & McDonnell, 2003), runoff generation and nitrate dynamics (Ocampo, et al., 2006) and overall catchment scale runoff response (Jensco, et al., 2010). In a forested environment, Jencso et al. (2010) demonstrated that the magnitude and timing of water and solute concentrations at the catchment outlet was controlled by the size (water storage in saturated zone), spatial arrangement of uplands and near stream zones along a stream network, and by the timing and duration of shallow groundwater connectivity between these areas. Such concepts have led to the development of a new generation of hydrological models capable of predicting water storage, levels, discharge volumes and solute pathways from a catchment (Smith, et al., 2012) (Tetzlaff, et al., 2014).

It is recognised that a sound analysis of groundwater flows and hydrological connectivity is essential to understand the movement of water and physical, chemical and biological transformations of solutes through the landscape in low order streams and headwater catchments. There is a need for research in to how continuous flow fields develop under sets of different environmental conditions to assist managers to know when and where to intervene in a catchment (Bracken, et al., 2013).

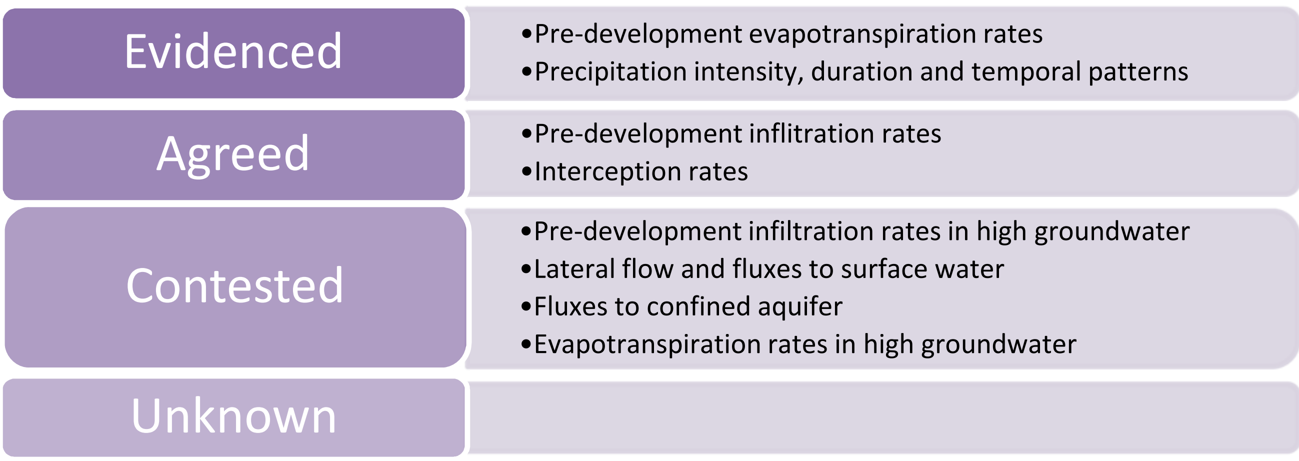

Figure 3 Pre-development water balance state of knowledge

2.1.2 Groundwater levels

Determination of pre-development groundwater levels and their fluctuation is a critical component of urban design, planning and management.

The following information is required for design and construction works in areas with shallow groundwater tables:

- Maximum groundwater levels over the life period of structures or urban areas.
- Maximum and minimum groundwater levels during construction and development.
- Historical minimum groundwater levels (for acid sulfate soil assessment).
- Groundwater level response to urbanisation.

DoW (2012) recommends up to two full years of groundwater level monitoring with at least monthly frequency, but it states that the monitoring duration for specific projects would depend on their potential risks and, therefore, can differ from the recommended duration. DoW (2012) provides little guidance on the spatial density and placement of bores. However, bore construction requirements are reasonably well addressed by guidelines in a number of Australian Local and State Government jurisdictions, usually in relation to contaminated site investigations.

A review of pre-development groundwater monitoring programs undertaken in Western Australia indicated little consistency in bore densities in high groundwater areas. Given the range of variables affecting groundwater levels and flows, monitoring programs need to be suitable for individual site conditions. Pre-development monitoring frequencies in Western Australian studies typically range from 15-minute to monthly. Sub-daily groundwater level response times suggest that monthly water level monitoring is likely to underestimate extremes.

There is also no standard (or agreed) methodology to determine pre-development groundwater levels. For different projects, different approaches are taken and those are often driven not by technical requirements, but by project budgets and schedules. While DoW (2013a) explains water resource factors that are impacting controlled groundwater levels, it doesn't recommend a methodology to determine maximum groundwater levels. A number of existing industry approaches are presented in Chapter 2.1.2.2.

The following sections summarise existing methodologies in research and industry to determine pre-development groundwater levels. Traditionally, although with some exceptions, researchers are using 3-D numerical models, while practitioners are applying 1-D numerical models or more simplified calculation methods. Limitations of the existing methodologies are described below, noting that these are widely recognised by most industry practitioners.

2.1.2.1 Sources of Information

The *Perth Groundwater Atlas* (Depatment of Water, WA, 2004) presents an interpolated groundwater surface constructed for May 2003 (seasonal minimum water levels) and a historical maximum groundwater surface that is based on measured maximum water levels in monitoring boreholes. As all boreholes have different record periods, the reported maximum groundwater surface is not related to any particular time and should therefore be considered "indicative only". Atlas explanatory notes state that the primary objective of the Perth Groundwater Atlas is to provide information to assist in the installation of groundwater abstraction bores and "because of changes in groundwater and natural surface levels that can occur over time … Department of Water is not in a position to guarantee the accuracy of the data".

Department of Water WIR system and other state and national databases (Department of Water and Environment Regulation, 2017). The WIR database contains historical water level monitoring records and stores data from bores, surface water and rainfall sites for Western Australia. This database is normally used to determine minimum and maximum groundwater table levels and seasonal variations on a site (subject to the availability of monitoring records) or in the site's proximity. The database monitoring records are also used to calculate AAMGL as explained below, which it is noted is not recommended for design purposes. There are other databases that were collated by DWER for specific projects and regions (e.g. Swan Coastal Plain). These databases are not available online but can be obtained on request from DWER. All States of Australia have their own water management information systems (see for example http://data.water.vic.gov.au/monitoring.htm for Victoria) that contain groundwater level observations. Based on the experience gained through several MSc research projects at the University of Western Australia, other than in WA these water information systems contain a limited number of measurements that provide any real assistance in understanding regional maximum groundwater levels. The Western Australia water information databases however (i.e. WIR system and more local databases) have a good spatial coverage and a fair number of bores with measurements, though to be included the data require significant time and resource investment for updates and quality checks. This is why much of the groundwater level measurements that have been conducted for various State infrastructure projects, such as Gateway WA or Forrestfield Airport Link, have not been included in WIR database.

Project-specific water levels monitoring data varies widely, both in spatial density and temporal frequency and duration.

2.1.2.2 Methodologies to determine pre-development groundwater levels

<u>Use of Perth Groundwater Atlas</u>

Despite known inaccuracies of the atlas (up to 3m (Zirakbash, et al., 2018)), it is often used for screening purposes (i.e. to determine whether a high groundwater table may cause risk and therefore needs to be investigated). DoW (2013a) clearly states that the Perth Groundwater Atlas “is not intended to define the groundwater regime for urban development”. Despite the above statement, some practitioners also use the Perth Groundwater Atlas for urban design purposes.

<u>Average Annual Maximum Groundwater Level (AAMGL)</u>

Even though the AAMGL approach is not mentioned in DoW (2013a) , it is a widely used concept in Western Australia for the determination of maximum groundwater levels and is used in subdivision, road construction and, in particular, for pavement design. Brookes (2016) mentions AAMGL in relation to selecting the invert discharge level of subsoil drains.

To estimate the pre-development AAMGL, annual groundwater peaks are averaged over several years. The peaks can either be measured locally on site or obtained from the WIR database. The Department of Environment Regulation has no guidelines in respect to calculating AAMGL (Davies, et al., 2004). The concept was criticised by practitioners over the last decade with major concerns related to the following (Davies, et al., 2004):

- Not accounting for existing drainage systems (e.g. deep surface drains) that are controlling the local groundwater table.
- Periods of averaging are not defined, this results in different periods of data being used by different practitioners or by the same practitioner on different occasions.
- Furthermore, the method does not account for long term trends in groundwater levels.

Further to their review of the AAMGL concept, (Davies, et al., 2004) proposed a Controlled Groundwater Level (CGL) be used in existing drainage systems. CGL is the invert level of groundwater controlling infrastructure (IPWEA, 2016).

<u>Back-calculation of recent measurements towards historical maximums</u>

After seasonal maximum groundwater tables are established locally, current practice is to estimate local maximum groundwater levels based on the closest monitoring borehole from the WIR database with a long-term record. Using local maximum data, design groundwater levels are typically established by adding a value corresponding to the:

- Difference between the maximum historical and seasonal groundwater levels at a borehole with long-term records.
- Difference between the estimated maximum and the seasonal maximum groundwater level at a borehole with long-term records. Estimated maximums can be higher or lower than historical maximums and they aim to balance the high additional costs associated with conservatism and the risk that these estimated groundwater levels will be exceeded (see (Boronina, et al., 2014) for Australian case study and (Socolow, et al., 1994) for USA case study).
- Difference between the AAMGL and the seasonal maximum groundwater level at a borehole with long-term records.

- Seasonal variations of the groundwater table for a future construction period are usually assumed to be the same as those during the monitoring period. Historical minimum groundwater levels are estimated based on long-term records in a similar way to the estimation of maximum groundwater levels.

2.1.2.3 Mathematical models

Time-series correlation analysis

Several research studies (e.g. (Almedeij & Al-Ruwaih, 2006) (Chen, et al., 2002)) have attempted to predict groundwater level fluctuations using established correlations with climatic variables. Even though some of the correlations demonstrate good matches between measured and calculated groundwater hydrographs, the applications of this method for most cases are limited because it doesn't explain how to determine:

- Maximum groundwater levels at key locations where no long-term hydrographs are available.

- Climatic parameters that will be associated with maximum groundwater levels.

Furthermore, time series analyses have a clear disadvantage of a lack of consideration of physical concepts in the analysis approach due to the inherent structure of the equations (Bidwell, 2005). Moreover, statistical and stochastic approaches of time series analysis cannot consider spatial variations of the hydraulic properties of an aquifer, land use, soil type and slope in areas of investigation. The above parameters are often important to consider for the determination of maximum groundwater levels.

Lumped-parameter models

Other studies (e.g. (Upton & Jackson, 2011)) have applied lumped parameter models to predict groundwater levels. Although these models may correctly represent concepts of groundwater flow and interactions of its components, they are usually not able to estimate groundwater table elevations at the level of accuracy and reliability required for urban development in areas with shallow groundwater tables.

Numerical models

A common view of practitioners is that, if reliable estimates of groundwater levels are required, a complex 3-dimensional groundwater flow numerical model needs to be developed. Such a model would have to be calibrated using local and regional data sets and parameterised in such a way that it will be able to predict either maximum or minimum groundwater levels as required. Though DoW (2013a) does not infer that groundwater modelling is required to calculate maximum groundwater levels, the document does encourage the use of numerical groundwater flow models for these purposes.

Recent project experience by the authors has suggested that, over recent years, no numerical model developed by industry or university researchers has been able to predict maximum groundwater levels with the reliability or accuracy required for urban development design purposes. Although most reviewed models were developed according to the Australian Groundwater Modelling Guidelines (Barnett, et al., 2008) and were deemed to be acceptable for descriptions of *regional* groundwater flows and *regional* environmental impacts, they have typically failed *local* validations and were not able to reliably predict maximum groundwater levels at *specific locations* (e.g. road alignments).

Using numerical models for the determination of the Design Groundwater Level (DGWL) may look appealing given the possibility to account for the inherent, and often significant, complexity of physical processes (e.g. surface-groundwater interactions near compensating basins) and the heterogeneity of aquifers (Barnett, et al., 2008). However, most regional models have uncertainties of 2-10 metres in the prediction of hydraulic heads. This uncertainty is acceptable for regional models, however it is excessive for civil structure design that may be influenced by groundwater level changes. In many cases, it is not possible to reduce the predictive uncertainty for regional models because it is controlled by parameters that are either difficult to measure (e.g. spatially-distributed Specific Yield) or their complex behaviour requires significant simplification. For example, natural (pre-development) recharge cannot be measured and it is controlled by several factors including rainfall, vegetation cover, land slope etc. In most groundwater models, the recharge value is just a “professional guess” that is based on general concepts, while exact numbers are usually not able to be justified.

Other uncertainties in modelling maximum groundwater levels are related to parameters for specific prediction periods. For example, even if predicted maximum rainfall is deemed reliable, its conversion into recharge rates as a percentage of daily rainfall (a common approach among practitioners) remains over-simplified, as in reality recharge rates depend on numerous factors as highlighted earlier.

While the importance of accurate determinations of maximum groundwater levels is widely recognised by practitioners, there is currently no standard and agreed methodology or even recommendation on what approach needs to be used.

> *“Models have their place, but they have been put in too much focus and too much dependence is placed on their results. I have already seen a number of litigation cases where models have been adopted and put in place and as soon as they got into Court they have been thrown out. It has become a really risky practice”*

Evidenced	• Pre-development groundwater levels fluctuate seasonally and due to storms
Agreed	
Contested	• Pre-development groundwater level bore placement and monitoring programs • Pre-development groundwater level determination
Unknown	

Figure 4 Pre-development groundwater levels state of knowledge

2.1.3 Water quality

2.1.3.1 Variability

The surface and groundwater quality of a pre-development environment is the product of the environmental characteristics of a site and its catchment (hydrology, soils, vegetation and topography) and pre-development land use (undisturbed or disturbed). Pre-development land use is a key consideration in identifying water quality pollutants and potential impacts on water resources and receiving environments within a catchment.

Nitrogen and phosphorus export from catchments commonly reflects the relative contribution (proportion) and location (spatial distribution) of their sources, which are related to catchment land uses (Carey, et al., 2013). Patterns of nutrient export have been extensively studied and reported from agricultural and forested environments (Creed, et al., 1996) (Aubert, et al., 2013) and some researchers have investigated transformations of mobile nutrients along specific flow pathways (Ocampo, et al., 2006). The N and P export patterns also reflect the different runoff generation mechanisms that control both water pathways and nutrient availability for transport;

these mobile nutrient species are subject to physical and biogeochemical transformation during transport along the pathways.

Greenfield urban expansion areas typically comprise rural or semi-rural properties and associated land uses. These broadscale land use types typically result in diffuse sources of water quality pollutants. On the Swan Coastal Plain, the introduction of trace element fertilisers in the 1950s led to widespread land clearing for the expansion of agricultural production (Kelsey, et al., 2011). In some areas, the long term application of these fertilisers has resulted in the accumulation of nutrients within the shallow soil profile, while in other areas the remnants of wetlands of the Swan Coastal Plain have resulted in elevated organic nutrient concentrations in the soil profile (Chapter 3.2.2). Land clearing may also result in increased salinity and the disturbance of acid sulfate soils within a catchment.

Urban fringe and rural land use localities are also likely to contain effective 'point source' polluting land use types such as intensive agricultural practices (e.g. intensive animal industry, horticulture).

2.1.3.2 Monitoring

Determination of pre-development water quality is important to assist with identifying issues that need to be addressed as part of the land development process, and to reduce the risk to both water resources and the development. Pre-development water quality is characterised by monitoring of site surface water and groundwater resources. The recommended standard timeframe for pre-development monitoring in greenfield areas of Western Australia is two full years before site works begin, where no historic monitoring record exists (Department of Water, 2012). In practice this is often interpreted as monitoring of water quality for two full winter groundwater level peaks, although different pre-development water quality monitoring approaches are often applied for different projects, with similar drivers to the pre-development groundwater level determination (these being project budgets and schedules). The duration of pre-development monitoring programs reported in reviewed water management plans ranged from reporting of a single monitoring event through to three years of monitoring, with varying frequencies of monitoring also reported.

In addition to variations in the duration of pre-development monitoring programs, other key issues include the spatial density and placement of bores to adequately characterise the pre-development environment, in particular groundwater monitoring where there is variation in subsurface conditions across the site. These decisions are generally made based on desktop assessments of site conditions, prior to geotechnical surveys of the site.

Water monitoring guidelines for better urban water management strategies and plans (Department of Water, 2012) recommends water quality parameters for monitoring at sites proposed for urban development, including general physiochemical parameters and nutrient forms. Organic nutrients are not considered in the guideline nutrient suite, with practitioners noting that the key parameter missing was total filtered nitrogen, which is used to determine dissolved organic nitrogen. It was further noted that a standard methodology for dissolved organic nitrogen should be specified in the guidelines as laboratories use different approaches.

A review of water management plans has identified that most pre-development water quality monitoring programs considered the nutrient suite recommended by the guidelines, with some also reporting dissolved organic nitrogen.

Practitioners also noted that pre-development monitoring programs should consider all potential water uses (e.g. managed aquifer recharge, or MAR) and receiving water bodies at the pre-development stage and not be limited to background water quality characterisation of water resources. Strategic planning at the regional scale may be required to support this.

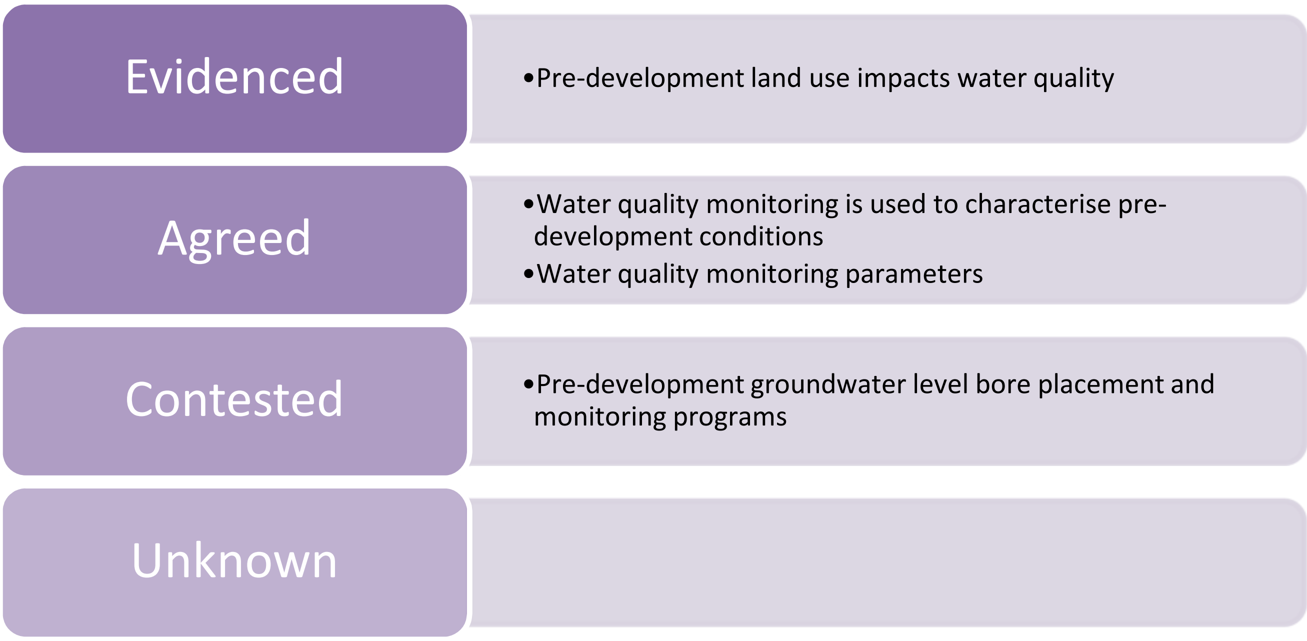

Figure 5 Pre-development water quality state of knowledge

3 Impact of development on water resources and environment

Urban systems impact water resources and the environment in areas with high groundwater. Current practices attempt to minimise this impact; however an incomplete understanding of pre- and post-development surface water and groundwater systems can result in residual impacts described in this chapter. Impacts are described both before and after implementation of current management measures, given the variability in current management measures, and the potential for these to change in future.

3.1 Water balance

Several hydrological changes occur when a catchment is urbanized, primarily through alteration of the proportions of overland, subsurface and groundwater flows. This is illustrated in Figure 6, where SCS is an abbreviation of Source Control Systems.

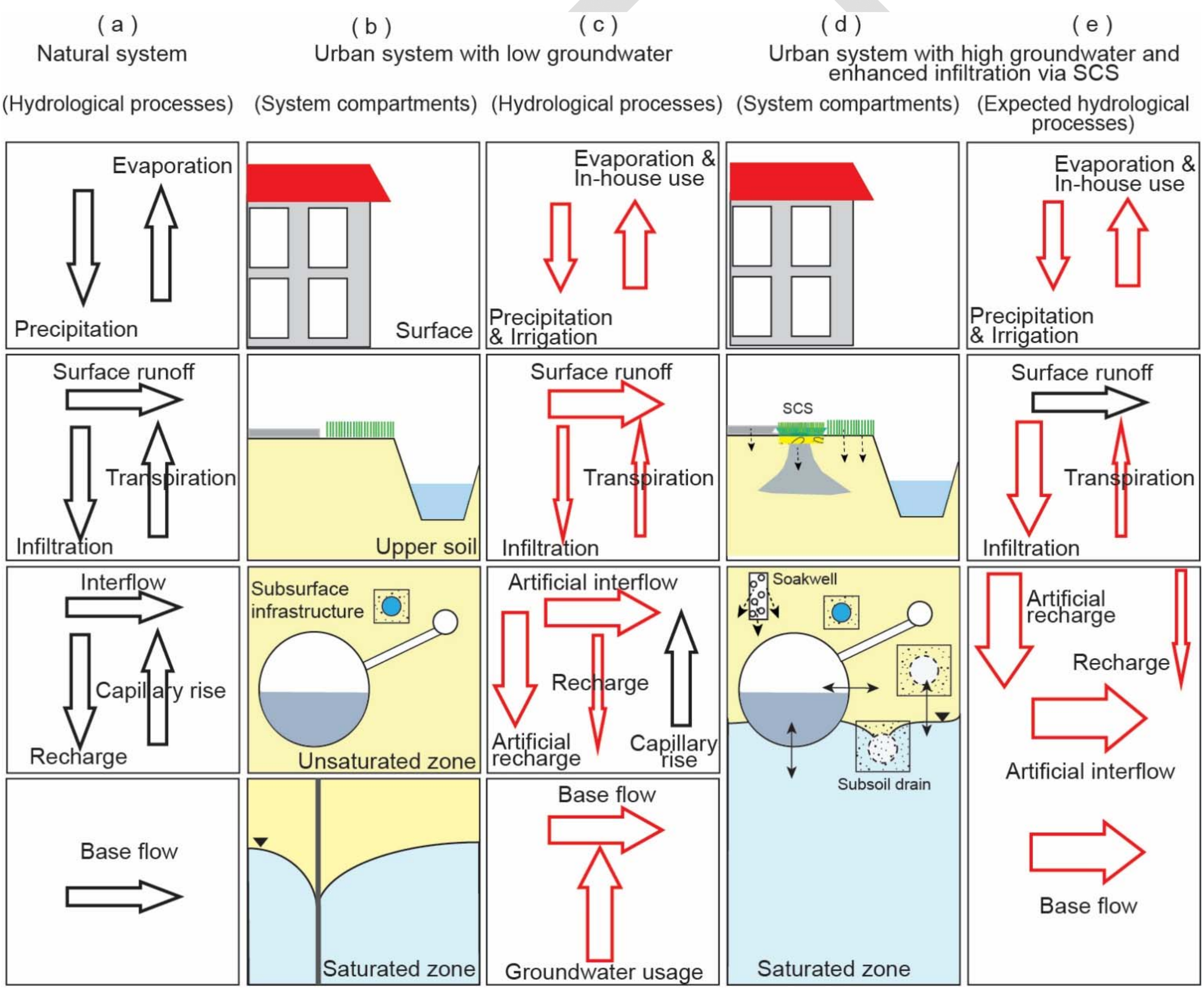

Figure 6 Conceptual model of perturbation of the urban water balance. Red arrows represent water flow that has been modified or introduced by urbanisation and proposed urbanisation in high groundwater environment with SCS. Modified after (Schirmer, et al., 2013).

3.1.1 Vegetation and evapotranspiration

Urbanisation alters vegetation types and coverage, and therefore transpiration rates. Vegetation also changes over time, with newer developments exhibiting less tree canopy cover and shallower root depth when compared to older developments. Urbanisation also alters soil and ground surfaces, and therefore evaporation rates. Barron et al. (2013) showed that urbanisation diminished evapotranspiration losses, which is supported by Hall et. al., (2010) and Marillier et. al., (2012)

Evapotranspiration rates can be measured or estimated using a variety of methods, including catchment water balance, energy balance, remote sensing, and eddy covariance. The CSIRO WAVES integrated energy and water balance model can predict evapotranspiration. This model was found to be sensitive to rainfall, Leaf Area Index, light extinction, and maximum vegetation rooting depth (Xu, et al., 2009). Whilst WAVES is suitable for use at the development scale, it requires detailed vegetation data that may not be available at the planning stage.

There is no evidence that WAVES has been used by industry to predict evapotranspiration at this scale. A review of published and unpublished water management strategies and plans in Western Australia indicated a range of post-development methods for estimating evapotranspiration, including:

- Nil, as a conservative assumption for groundwater level prediction;
- Bureau of Meteorology monthly potential evapotranspiration rates;
- Bureau of Meteorology monthly pan evaporation rates;
- Engineering estimates; and
- Estimates incorporated into irrigation demands.

"Development reduces evapotranspiration and increases groundwater recharge, particularly into imported sand fill"

"you can use Penman Eq. to get a rough evapotranspiration estimate"

Evidenced	• Urbanisation alters vegetation cover, soils and ground cover
Agreed	
Contested	• Post-development evapotranspiration rates
Unkown	• Methods for predicting post-development evapotranspiration rates

Figure 7 Post development water resources: vegetation and evapotranspiration state of knowledge

3.1.2 Groundwater table

Urbanisation often causes increases in groundwater levels due to higher post-development net recharge rates (Applyard, 1995) (Davies, et al., 2014) (Silberstein, et al., 2009) (Xu, et al., 2009). The higher net recharge is associated with a decrease in evapotranspiration (Barron, et al., 2013) and, in Western Australia, an increase in runoff infiltration from paved surfaces due to the provision of infiltration measures (soakwells).

In developing countries, increases in groundwater levels also occur due to leakage from water distribution networks and exfiltration from sewage systems and waste water disposal pools (Abu-Rizaiza, 1999) (Al Sefry & Sen, 2006).

Other studies, outside of WA, suggest that urbanisation can lower groundwater tables due to decreased groundwater recharge over the areas with impervious surface cover (Leopold, 1968) (Ferguson & Suckling, 1990) (Rose & Peters, 2001) (Konrad, et al., 2005) (Hardison, et al., 2009). The difference can be attributed to differences in urban water management practices (i.e. no soakwells) and varying hydrogeological conditions between regions.

Groundwater levels may also rise or fall in response to the construction of underground structures (e.g. published case study by (Bob, et al., 2015). The impact of underground structures on groundwater flows and levels was reviewed by (Attard, et al., 2016). This review concludes that underground structures can:

- Impede the natural flow of the groundwater, which may result in rising water levels upstream and falling water levels downstream of the underground structure.

- Disturb the groundwater flow system, which may result in additional drainage and consequently lowering groundwater table.

Despite evidence of the variety and complexity of responses of groundwater tables to urbanisation, little guidance exists on how to predict the impact of urbanisation on groundwater balance and water levels for specific cases. This gap in research and methodology is stated by (Bhaskar, et al., 2016).

Numerous academic and some industry studies use numerical models (see (Davies, et al., 2014) for a case study in Western Australia and (Gattinoni & Scesi, 2017) and (Goebel, et al., 2004) for case studies in Europe (Italy and Germany)) or other types of mathematical models (e.g. 1D analytical equations - (Serafini, et al., 2014)) to assess the impact of urbanisation on groundwater tables. Modelling approaches for urban catchment hydrogeology are listed and explained in Table 2 of (Salvadore, et al., 2015). Most of the listed models include water level predictions as parts of their algorithms.

As explained in Chapter 2.1.2.3, the application of mathematical models, even for pre-development conditions, faces challenges of predicting groundwater levels at local scales, when a local feature (e.g. a clay lens or constructed feature) can impact model outcomes more than the regional properties that are determined during model calibration.

Predicting groundwater flows and levels for post-development conditions is associated with additional challenges that are summarised in detail by (Salvadore, et al., 2015) and (Van de Ven, 1990). In urban catchments, groundwater flow components interact with each other in multiple ways and at various temporal and spatial scales. These interactions are very difficult to impossible to quantify or sometimes even determine conceptually for water balance, as, for example, leakages from sewers and water mains. In particular, urban recharge is a crucial water balance component in urban catchments. However, the determination of such recharge usually has high uncertainty, both, spatial and temporal. Vazquez-Sune, et al. (2005) contains a good summary of the sources of such uncertainty in the determination of urban recharge rates and also describes methods of recharge quantification. The latter review states that the most reliable methods of recharge quantification involve the calibration of mass-balance models by chemical species associated with known sources. While this approach would bring the most reliable recharge rates and, consequently, predicted post-development groundwater levels, it requires time, skills and funds that are rarely available for practical applications. Furthermore, not every site may be associated with chemical tracers that help estimate recharge rates.

Calculating groundwater levels for post-development conditions generally focuses on two aspects:

1) How much will the groundwater level rise due to the extra recharge from urban areas or other post-development changes (e.g. cutting pine plantations), and at what stage do we need to start thinking about using subsoil drains to control groundwater levels; and

2) How water levels will be impacted by subsoil drains if they are constructed; this will help guide fill requirements

The IPWEA (2016) guideline methodology only really addresses the second aspect of post-development water levels. It states that modelling is required for designing groundwater drainage systems that must predict the performance of the system and provide average and peak discharges through the system. The required models may vary from steady state, spreadsheet-based, models to numerical 1, 2 or 3-dimensional models, however there is little guidance on model selection and the required level of complexity. Whilst drawdown and mounding effects can be reasonably well estimated by 1D models for most hydrogeological conditions, absolute water table levels at distances from a drain (i.e. near a model boundary) will remain inaccurate. IPWEA (2016) recommends setting up local boundaries based on publicly available regional models (i.e. Perth Regional Aquifer Modelling System (PRAMS) (2009), Peel Harvey Aquifer Modelling System (PHRAMS) or South West Aquifer Modelling System (SWAMS)). However, the referenced models, as reported in their explanatory notes, may have predictive uncertainties of up to 10 m or even higher. This uncertainty may or may not impact drainage systems predictions.

IPWEA (2016) doesn't provide any qualitative or quantitative criteria of model performance or requirements to address model uncertainty. The document also contains recommended recharge rates, however, the base or justification of the selected recharge rates is not explained.

Numerous studies (e.g. (Schirmer, et al., 2013)) recognise the low reliability of predictions of groundwater flow and levels in urban catchments. Schirmer, et al., (2013) states that "the high level of complexity and parameter uncertainty as well as structural uncertainty remains a major problem of coupled and integrated model applications". Rather than using numerical models in a standard way, i.e. trying to model a real system with all its features, as described in Australian Groundwater Modelling Guidelines (Barnett, et al., 2012), numerical models could be used in a more holistic way with particular focus on better conceptualisation and quantification of the most important site-specific processes and parameters. Model objectives would have to be stated more specifically beforehand to explain what models are expected to achieve and what wouldn't be achieved. Probabilistic modelling approaches can help to better account for parameter uncertainty.

Where groundwater controls are proposed, such as those described in Chapter 4.3.3, maximum groundwater levels are generally agreed. Whilst drain spacing is known and hydraulic conductivity generally agreed, infiltration and recharge rates can be a source of uncertainty.

“For post-development, we work on 60-70% [recharge] of rainfall total”

“One study used 35% [recharge] for both pre and post development”

Evidenced	• Post-development goundwater levels fluctuate both seasonally and due to storms
Agreed	• Post-development groundwater levels with groundwater controls
Contested	• Post-development groundwater levels without groundwater controls • Post-development recharge rates • Methods for predicting post-development groundwater levels
Unknown	

Figure 8 Post development water resources: groundwater levels state of knowledge

3.1.3 Water and sewer

Potable water used for garden irrigation and other outdoor water uses increases the recharge of groundwater and therefore water table levels. For Perth, annual outdoor water use for single residential houses is 707 L/house per day, compared to multi residential use of 389 L/house/day (Loh & Coglan, 2003). More recent estimates of 605 ML/annum have been made, which equates to 552 L/house/day (GHD Pty Ltd, 2008). It is noted that demands in both estimates don’t distinguish between water sources, whether potable water, garden bores, or rainwater tanks. Furthermore, there are uncertainties related to how much water is consumed by the vegetation, evaporated, or recharged.

Sewerage systems can both leak into groundwater and also receive groundwater inflows. In a high groundwater environment, the hydraulic head difference increases the potential for groundwater inflow into sewer systems, although there are several variables related to the age and condition of pipe, pipe material and joints, relative groundwater levels, soil properties, and the presence of tree roots that make quantification of this process difficult. Where sewers are located above the groundwater, leakage from sewers into groundwater is more likely.

“10% of metro Adelaide groundwater levels are controlled by the sewers”

Leakage from water pipes in Melbourne and Perth is estimated at 8% and 7% respectively of the urban water supplied (Bureau of Meteorology, 2012). This leakage adds to the groundwater balance, increasing groundwater levels.

Evidenced	• Potable water used for irrigation adds to groundwater balance • Potable water leakage adds to groundwater balance
Agreed	• Gravity sewer systems remove water from groundwater balance in high groundwater environments
Contested	
Unknown	

Figure 9 Post development water resources: water and sewer state of knowledge

3.1.4 Water Dependent Ecosystems

Water dependent ecosystems are reliant on specific water regimes to maintain their ecological values, including species composition and ecological processes, as well as their economic, social and cultural values. Where urban development occurs in proximity to water dependent ecosystems, it has the potential to alter the pre-development site water balance, and therefore the water dependent ecosystem water regime (e.g. water quantity, level, period of inundation) outside the range of normal seasonal/climatic variability.

Urban development has the potential to alter a site water balance via several means including:

- Increasing recharge to groundwater (e.g. localised infiltration as outlined in Chapter 3.1.7; loss of deep rooted vegetation; irrigation of POS and private household irrigation via reticulated/scheme water).
- Localised decline in pre-development groundwater levels (e.g. drawdown associated with local groundwater use for irrigation of POS and private household demand via bores).
- Decline in groundwater levels and recharge (e.g. through groundwater controls as outlined in Chapter 3.1.8).

Land form modification (e.g. cut to fill) also has the potential to alter the local water balance through alterations of the local catchment hydrology and therefore the water regime of water dependent ecosystems (Monk, 2006); (Department of Water, 2010 b). The effect of this was modelled for selected wetlands in the Murray region (Department of Water, 2010 b) however it is uncertain if impacts have been measured in the field.

Urban development also has the potential to degrade water quality levels in water dependent ecosystems through the mobilisation of accumulated stored nutrients (Chapter 3.2.2), the introduction of pollutants (Chapter 3.2.1) and adverse impacts associated with acid sulfate soils (Chapter 3.2.3).

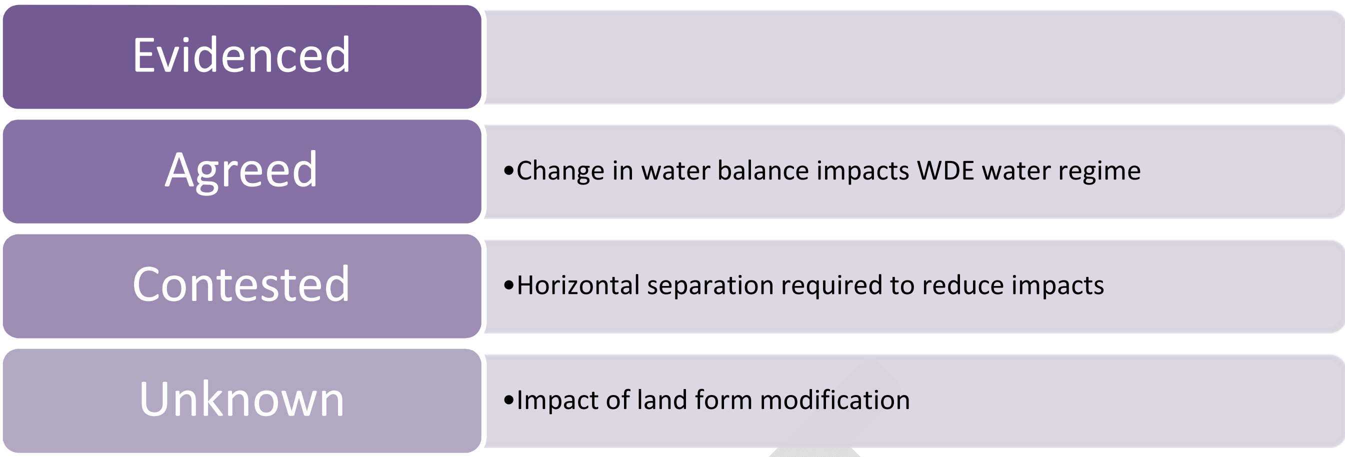

Figure 10 Post development water resources: water dependant ecosystems state of knowledge

3.1.5 Impervious surfaces

Impervious surfaces can be divided into (Ball, et al., 2016)

- Directly Connected Areas, defined as impervious areas (e.g. roofs and paved areas) which are directly connected to the drainage system – referred to as Directly Connected Impervious Areas (DCIA); and
- Indirectly Connected Areas, defined as:
  - Impervious areas which are not directly connected, runoff from which flows over pervious surfaces before reaching the drainage system (e.g. a roof that discharges onto a lawn) – referred to as Indirectly Connected Impervious Areas (ICIA); or
  - Pervious areas that interact with Indirectly Connected Impervious Areas, such as nature strips, garden areas next to paved patios, etc.

Urbanisation results in impervious surfaces replacing vegetated landscapes and this (Ball, et al., 2016):

- Decreases the storage of water within soil profiles and on the ground surface and so increases the proportion of rain that runs off;
- Increases the velocity of overland flow; and
- Reduces the amount of rainfall that recharges groundwater.

Prior to current practices of runoff attenuation, urbanisation causes up to a 10-fold increase in peak flows of floods in the range of 1 to 4 Exceedances per Year (EY), with diminishing impacts on larger floods (Tholin & Keifer, 1959) (McPherson, 1974), (Hollis, 1975) (Cordery, 1976) , (Ferguson & Suckling, 1990)

Initial losses for gauged, traditionally designed, urban catchments in Australia are concentrated near 0mm, whilst gauged rural Australian catchments have a mean initial loss of 32mm, as illustrated in Figure 11. Continuing losses for DCIA can be assumed to be zero (Ball, et al., 2016). This is in contrast to double ring infiltrometer measurements of infiltration through impervious surfaces, which led the authors to conclude that within the study catchment, impervious surfaces infiltrate 21% of annual rainfall (Wiles & Sharp, 2008). However, the link between pavement fracture, hydraulic conductivity and infiltration rates is weak, so the findings are discounted.

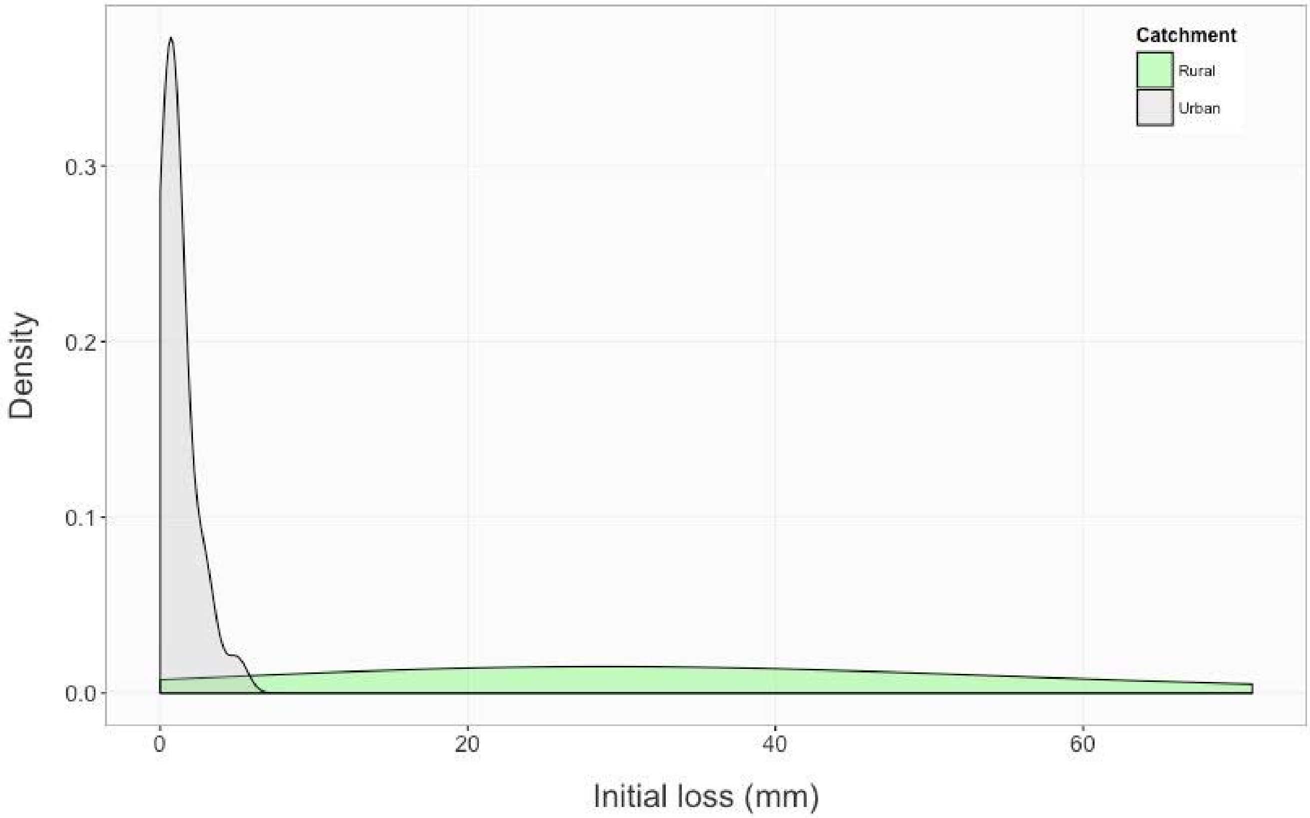

Figure 11 Comparison of Initial Loss in Urban and Rural Catchments (Ball, et al., 2016)

Runoff rates and volumes from indirectly connected impervious surfaces are evidenced to lie between rural catchment rates and connected impervious urban catchment rates. Initial and continuing losses of 40% to 80% of recommended rural catchment losses are recommended by AR&R (Ball, et al., 2016). AR&R does not publish rates for high groundwater environments.

In contemporary Australian urban developments, management measures such as on-site-detention and infiltration are implemented in the majority of cases. Thus, findings by (Wills & Davies, 2015) conclude that management measures and the use of indirectly connected impervious surfaces can produce zero surface water runoff at the lot scale. Specific factors such as the whether the driveway slopes to the road or to the lot can make the difference between a connected and indirectly connected impervious catchment.

In high groundwater environments, impervious surfaces significantly reduce recharge and increase runoff, in the absence of other urbanisation factors such as changes in evapotranspiration and stormwater disposal methods. However, where groundwater levels (saturated zone) are at or very close to the surface, runoff rates are already high, so impervious surfaces are concluded to have a lower impact on runoff and recharge rates. There is a lack of literature specifically addressing surface water runoff rates in areas of high groundwater, particularly where groundwater causes seasonal inundation, and how this changes because of impervious surfaces.

Evidenced	• Impervious surface impacts on water balance in low groundwater environments
Agreed	
Contested	• Impervious surface impact on water balance in high groundwater environments • Runoff coefficients • Continuing losses in high groundwater environments
Unknown	

Figure 12 Post development water resources: impervious surfaces state of knowledge

3.1.6 Rainwater tanks

Rainwater tanks are known to reduce surface water runoff volumes by capturing roof runoff and storing the water for indoor or outdoor uses. Indoor use of rainwater diverts the water to the sewer system, reducing either runoff volumes or groundwater recharge volumes. Outdoor use of rainwater returns the water to the environment, either as runoff, infiltration or evapotranspiration, usually long after the rainfall event. Due to the variability of roof sizes, tank sizes, beneficial uses, and associated temporal demands, the potential beneficial impact of rainwater tanks on the groundwater balance is considered contested. Some researchers are strongly in favour of these devices while others are less so. It is safe to conclude that further work (primarily appropriately configured and monitored test cases) is required to quantify the benefits of rainwater tanks on groundwater levels in high groundwater environments.

Practitioners usually ignore the effects of stormflow attenuation offered by rainwater tanks, on the basis that they are assumed to be full prior to a stormflow event. This is documented in the Queensland Urban Drainage Manual (Department of Energy and Water Supply, April 2013), however the literature to support this practice is lacking.

Evidenced	
Agreed	
Contested	• Rainwater tanks impact on water balance
Unknown	• Rainwater tanks impact on stormflow

Figure 13 Post development water resources: rainwater tanks state of knowledge

3.1.7 Localised infiltration

Infiltration systems capture and store stormwater runoff prior to infiltrating into the soil. The storage can be located at the surface, such as in basins and swales, or underground, such as in tanks, trenches, and soakwells. In all systems, infiltration rates are a factor of soil permeability, hydraulic head, groundwater levels, antecedent moisture conditions and device specific aspects such as the dimensions of the soil-water interface and blockage considerations. Storage volumes are a factor of infiltration rates, starting water levels and the volume and shape of the storm hydrograph.

Infiltration is used to counteract the effects of impervious surfaces on recharge. It is evidenced that the use of infiltration devices causes local increases in groundwater levels (Machusick, et al., 2011). The duration and extent of this mounding is dependent on the inflow hydrograph, infiltration device geometry and soil and groundwater conditions. Practitioners have attempted to estimate such mounding using either (IPWEA, 2016):

- Steady state calculations, typically using variations of the Houghoudt equation
- Dynamic 1-dimensional models; or
- Detailed 2-dimensional or 3-dimensional models.
    - Groundwater modelling, as discussed in Chapter 2.1.2.2.

If infiltration is likely to be a stormwater disposal method, practitioners usually undertake pre-development infiltration testing using one of the following methods:

- In-situ constant head or falling head permeameter tests.
- Laboratory constant head or falling head saturated hydraulic conductivity.
- Auger hole slug tests to estimate saturated hydraulic conductivity.
- Estimations of saturated hydraulic conductivity based on particle size distribution.

The difference between hydraulic conductivity and infiltration rates is an important distinction, with practitioners applying a variety of adjustments to hydraulic conductivity to estimate infiltration rates, such as the factors proposed by Argue (2005) and Coffey (2010) .

Infiltration devices are at risk of blockage from debris and fines transported from runoff. Best practice is to provide pre-treatment prior to discharge into the infiltration device, particularly those with restricted access for maintenance. Open basins are frequently configured without pre-treatment, but with a maintenance schedule to remove sediment and debris build-up. Vegetation in basins, biofilters and other devices helps maintain the infiltration capacity and prevent clogging (Payne, et al., 2014).

There are little published reports on the accrual rates and characteristics of blockage material from urban catchments, probably due to the wide range of contributing factors, such as vegetation density and type, topsoil characteristics, seasonal factors, gross pollutant generation rates and associated land uses, and frequency of street sweeping. There are anecdotal reports of infiltration device failures due to blockage.

A review of published and unpublished Urban Water Management Plans in Western Australia reveals inconsistency amongst practitioners on methods for estimating blockage. Cocks (2007) proposes a calculation based on a clogged base layer, whilst practitioners have applied reductions to the measured infiltration rate to account for blockage. Blockage processes and rates are therefore considered contested.

Evidenced	• Concentrated infiltration causes local increases in groundwater level
Agreed	
Contested	• Infiltration device infiltration rates • Infiltration device blockage rates
Unknown	

Figure 14 Post development water resources: infiltration measures state of knowledge

3.1.8 Importation of fill and groundwater controls

Fill is often imported in areas of high groundwater for the reasons discussed in Chapter 4.3.1. Fill increases the available groundwater storage and head, although the ability of groundwater levels and volumes to increase depends on how the water balance changes post-development. Subject to fill properties and pore size, increased fill can also generate capillary rise. In the greater Perth region, fill is typically a granular material imported to site from an external borrow pit. Granular, non-hydrophobic, materials have a high infiltration potential, for both pervious precipitation losses and stormwater disposal. Subject to the method and configuration of stormwater disposal via infiltration, and changes to vegetation, importation of fill has the potential to increase recharge into superficial aquifers.

Groundwater controls such as subsoil drains, pumping systems and open drains lower or control groundwater levels by removing water from an aquifer and discharging it to surface water systems or making it available for other uses. Groundwater levels fluctuate daily and seasonally as discussed in Chapter 2.1.2. When groundwater controls are constructed below the maximum recorded or predicted groundwater level, they act to limit or control groundwater fluctuations. When installed below the minimum recorded or predicted groundwater level, they lower groundwater levels.

Practitioners set the spacing and hydraulic capacity of subsoil drains, pumping spears, and open drains using the methods outlined in Chapter 4.3.3. Groundwater level fluctuations still occur during recharge events, however the change in the phreatic surface is significantly dampened by the controls. Groundwater controls increase surface water discharge and decrease aquifer storage.

Groundwater controls used in combination with imported fill will increase surface water discharge and decrease aquifer storage if the groundwater controls are installed below the pre-development maximum groundwater level, but have negligible impact on aquifer storage if installed above the pre-development maximum groundwater level.

Evidenced	
Agreed	• Granular fill increases infiltration potential • Groundwater controls remove water from groundwater balance
Contested	• Continuing losses in sand fill • Long term performance and maintenance of subsoil drains • Rates of runoff from groundwater controls for different soil types, lot sizes, etc.
Unknown	

Figure 15 Post development water resources: imported fill and subsoil drainage state of knowledge

3.1.9 Managed Aquifer Recharge (MAR)

Managed aquifer recharge is the intentional recharge of water to suitable aquifers for either subsequent recovery and reuse or to achieve environmental benefits (Standards Australia, 2011) (Government of Western Australia; Department of Water and Environment Regulation, n.d.). When used primarily for recovery, this technique is also often referred to as Aquifer Storage and Recovery (ASR) or Aquifer Storage Treatment and Recovery (ASTR).

Common sources of water for MAR and ASR/ASTR include:

- Stormwater
- Subsoil drainage
- Wastewater

Water may be stored in superficial or deep aquifers. Subject to health, environmental and operation considerations, the quality of the source water, and the intended use of the water, a range of treatment measures may be required.

Once the source water flow rates and qualities are known, impacts on groundwater levels, flows and quality are generally agreed, and usually demonstrated through groundwater models.

There is a lack of literature on the water quality requirements for long term injector well operations. GHD (2016) suggested tertiary treatment is required to maintain feed water suspended solids to concentrations below 5 mg/L. Furthermore, injector well backwash requirements are also unknown. Department of Water (2016) identified the risk of clogging due to chemical reactions.

In shallow groundwater environments, superficial aquifers can be used for both disposal of stormwater and extraction for beneficial use, such as irrigation, when the water quality is fit-for-purpose. Aquifer recharge of superficial aquifers is typically undertaken through infiltration, and can also be via injection wells. The impacts of infiltration on groundwater levels and water balance is discussed in Chapter 3.1.5.

Methods employed by practitioners to quantify recharge rates are subject to the limitations of runoff predictions described in Chapter 3.1.5, together with the limitations of predicting the infiltration rate and the capacity of the aquifer to accept the recharge volume and rate. Following a slug test, the capacity of the aquifer is usually predicted using numerical models, with the limitations and uncertainties of these described in Chapter 2.1.2.3. Slug tests or pump tests are also used to predict aquifer recovery rates, together with numerical and demand modelling.

Evidenced	• MAR adds water to the target aquifer water balance
Agreed	• Impacts to groundwater levels, flows and quality
Contested	
Unknown	• Clogging potential and rates • Backwash requirements

Figure 16 Post development water resources: MAR state of knowledge

3.2 Water quality

3.2.1 Pollutant sources and transport mechanisms

Urbanisation introduces a range of new pollutant sources to a catchment and, when combined with higher runoff volumes, has the potential to increase pollutant loadings to surface and groundwater resources. The complexity of subsurface urban hydrology is acute in catchments with significant groundwater-surface water interactions and it has implications for nutrient fate and transport.

Some studies have reported that urbanisation increased solute concentrations in baseflow (i.e. flows through the drain network between rainfall events) and increased nutrient export from urban catchments (Rose, 2007); (Barron, et al., 2010); (Janke, et al., 2014); (Gabor, et al., 2017). These nutrient exports have been attributed to increases in groundwater discharge and possibly also the release of effluent from old septic tanks within the catchment. However, other studies have stressed the poor understanding of mechanisms controlling nutrient export via subsurface pathways in urban catchments and found no significant difference between baseflow and stormflow nutrient concentrations and loads (Taylor, et al., 2005); (Shields, et al., 2008).

The *Survey of nutrient inputs on the Swan Coastal Plain*, completed by the Department of Water in 2006, quantified nutrient inputs for urban residential land in metropolitan Perth and regional centres. The survey found that key nitrogen inputs were from gardens (70%), lawns (21%) and pets (9%), with similar findings for phosphorus with key inputs from gardens (81%), lawns (12%) and pets (7%). The survey further found that medium sized lots (601-730 m^2) had statistically greater nutrient inputs than both smaller and larger lots, with new homes applying significantly more nutrients than older homes (Kelsey, et al., 2010).

Barron et al. (2010) identified key nutrient sources within urban catchments of the greater Perth region as wet and dry atmospheric deposition (e.g. rain and dry fallout), inorganic and organic fertilisers in private gardens and public open spaces, and vegetation decomposition.

These findings are supported by recent research of sources and mechanisms controlling nutrient transport in medium to high density residential catchments in Tampa Bay (Florida, USA) (Yang & Toor, 2017). The study concluded that 50% of nitrate was contributed by atmospheric deposition, 33% by fertilizer, and that primary phosphate sources were desorption from natural sediments and the degradation of organic materials (leaves, grass).

While overall contribution of nutrients from urbans areas can be small on a catchment basis, the intensity of fertilisation in urban areas creates far higher nutrient loads per unit area when compared to the agricultural land uses (such as cattle grazing, cropping or mixed grazing) that urban development typically displaces (Kelsey, et al., 2010) (Hall, 2010). It is suggested that reducing urban lot sizes will reduce householder fertiliser application and nutrient export on a lot basis (Bowman Bishaw Gorham , 2002) (Kelsey, et al., 2010), with broad practitioner agreement. There is also potential for water quality to improve with a change in land use, particularly where the pre-development land use is an intensive animal industry (e.g. piggery or poultry farm) or contaminated site.

Urbanisation results in altered water quality characteristics and temporal variability in the receiving surface waters, due to changes in runoff generation processes, pathways and the spatial distribution of nutrients associated with urban development (i.e. at-source infiltration, leakage from sewer and mains drainage, septic tanks, fertilisation and the irrigation of private gardens and parks) (Ocampo, 2017). Within an urban environment, elevated recharge rates result in a higher water table, a decline in travel time from nutrient source to water table and shorter travel times in the unsaturated zone (Ocampo, 2017).

Unconfined aquifers are more vulnerable to contamination by urban development, particularly where their vadose zone is thin and their water table is shallow (Foster, et al., 1998). Rising groundwater levels associated with urbanisation may mobilise nutrients in the soil profile making receiving water resources more vulnerable to contamination by human disturbances. Introduced fill has the potential to increase travel time to groundwater compared to pre-development conditions, however water movement through soils with high hydraulic conductivity or macropores can also result in short travel times that do not allow sufficient time for nutrient interaction with the soil matrix, constraining biologically mediated processes in the unsaturated zone. Where groundwater controls are installed these also reduce the travel time in the saturated zone, and therefore the potential for nutrient attenuation in the aquifer (Chapter 3.1.8).

Where groundwater abstraction results in major changes to the hydraulic head distribution within an aquifer, this may result in the reversal of groundwater flow directions, leading to potential sea water intrusion and water quality deterioration. The effect of saline intrusion is quasi-irreversible, with salinity diffused into pore-water taking decades or potentially longer to elute (Foster, et al., 1998).

The impacts of urban development on post-development water quality is measured through water quality monitoring. In Western Australia, the recommended timeframe for post-development monitoring of each stage of subdivision (following completion of the last lot) is three full years depending on the level of risk (Department of Water, 2012). Actual post-development monitoring periods vary depending on local government handover requirements, resources (financial and personnel) as well as delays in completion of subdivision. With regard to post-development monitoring, local practitioners noted that:

- Three-year monitoring periods are insufficient to assess the impact of development and the nutrient retention efficacy of WSUD elements in areas of shallow groundwater.

- Better use of existing post-development monitoring data would assist in assessing modelling predictions of the impacts of urban development, as well as to evaluate if WSUD works in areas of high groundwater. This would require strategic coordination (the CRC could be well placed to help in this regard).

The limited availability of post-development water quality data in Western Australia has been acknowledged as a constraint to assessing the potential use of subsurface drainage water for MAR (Kretschmer, et al., 2011).

Evidenced	• Urban development impacts water quality • Urban development has high nutrient load compared to low intensity agriculture • Fertiliser is key nitrogen input in sewered urban development
Agreed	• Shallow groundwater shortcircuits nutrient pathway between source and receiving water resource • Groundwater controls reduce groundwater residence time and potential for nutrient attenuation
Contested	• Duration of post-development water quality monitoring
Unknown	• Post-development water quality

Figure 17 Post development water resources: pollutant sources state of knowledge

3.2.2 Pre-development nutrients

Areas on the urban fringe that are landmarked for future urban development in the greater Perth region typically comprise rural or semi-rural properties and associated land uses. Pre-development water quality monitoring (Chapter 2.1.3.2) within these urban fringe areas frequently identifies high total nutrient concentrations (primarily total nitrogen) within the shallow soil profile. Barron et al. (2010) note that in areas of shallow groundwater, nutrient concentrations are frequently dominated by organic forms, with inorganic species typically removed through nutrient transformations (nitrification, denitrification) and plant uptake associated with higher groundwater residence times.

These high concentrations are often attributed to nutrient accumulation due to historic agricultural land use practices (referred to as legacy nutrients) however there is emerging research that indicates that the high pre-development nutrient concentrations may be linked to broader characteristics of the Swan Coastal Plain.

Petrone et al. (2009) examined dissolved organic nitrogen (DON) concentrations in ten major sub-catchments of the Swan Coastal Plain from a mix of forest, agricultural and urban land uses, finding high proportions of DON in both agricultural and urban catchments. This research is supported by a recent groundwater sampling survey of 108 groundwater bores distributed across diverse land use, soil and vegetation complexes of the Swan Coastal Plain. The survey found that in more than two-thirds of the 108 bores, the total nitrogen concentration was made up predominantly of DON (Sobia Ahmed pers. comm., PhD student University of Western Australia).

An alternate suggestion to the legacy nutrient terminology is that the broad spatial distribution of wetlands on the Swan Coastal Plain (existing and destroyed/degraded) and the disturbance of historic wetland sediment nutrient stores because of land development may be a cause of elevated pre-development nutrients. Wetlands comprise more than 25% of the land surface of the Swan Coastal Plain, playing an important role in nutrient cycling for connected groundwater and surface water resources, with wetland sediments considered to be a major long-term store of nutrients.

Balla (1994) estimated that 80% of the wetlands of the Swan Coastal Plain have been lost or severely degraded. Many areas on the urban fringe of the Swan Coastal Plain are also areas of high groundwater, which historically comprised a series of shallow wetlands occurring as seasonally waterlogged flats or basins. Further research is required to assess the link between historic land use practices, historic wetland distributions and elevated pre-development groundwater nutrient concentrations. The source of elevated pre-development nutrients is therefore considered contested.

> *"It would be good if we could move past the terminology of legacy nutrients….reference to pre-development nutrients also infers a link to landuse, whereas its just the groundwater conditions"*

Regardless of the source of high nutrient concentrations in pre-development groundwater, the urban fringe of metropolitan Perth predominantly comprises areas of high groundwater, which may once have featured seasonally inundated wetlands - but now consist of rural or semi-rural land uses. As a result, there are a number of potential future urban development sites within areas of high groundwater that are likely subject to elevated pre-development nutrient conditions. While uncertainty about the risk that organic nutrients pose to receiving environments has been reported (Barron, et al., 2010), research has identified labile DON concentrations greater than dissolved inorganic nitrogen concentrations in major sub-catchments of the Swan Coastal Plain, highlighting its importance as a readily available source of nitrogen for in-stream and estuarine primary production in urbanising coastal catchments (Petrone, et al., 2009).

The dominance of organic forms of nutrients is identified as a concern for design of WSUD elements, which are typically designed to target inorganic and particulate forms of nutrients. In particular, unlined WSUD elements do not provide redox conditions and residence times to allow nutrient transformation to occur.

In shallow groundwater environments, it is generally agreed that improvement of site drainage through localised infiltration (Chapter 3.1.7) and groundwater controls (Chapter 3.1.8) have the potential to mobilise nutrients by reducing travel times and opportunities for nutrient transformation. De-watering activities associated with development may also mobilise pre-development nutrients.

Elevated pre-development nutrient concentrations have been reported to decrease three to five years after development (The Civil Group, 2015), with this finding supported by numerical modelling of the potential mobilisation of pre-development nutrients which suggested that the full impact of urbanisation on water quality may take up to five years to be realised (Barron, et al., 2010)

Key contested areas regarding pre-development nutrient concentrations relate primarily to the governance and selection of post-development water quality targets. Agreement on the management of pre-development nutrients should be resolved prior to development to ensure roles and responsibilities for management are clearly understood. Post-development water quality guidelines or targets are frequently defined by receiving waterway water quality targets (Department of Water, 2012), load reduction approaches or by the principle of maintaining or enhancing existing water quality (Western Australian Planning Commission, 2008). The applicability of these various water quality targets may be compromised by the potentially long time frames for the full impact of urban development on water quality to be realised, including timeframes for migration of pre-development nutrients in groundwater and potential for up-gradient contributing sources.

Evidenced	• Elevated pre-development nutrients frequently dominated by organic nitrogen
Agreed	• Elevated pre-development nutrients common where pre-development land use is rural or semi-rural • Organic nutrient forms difficult to treat using unlined bioretention WSUD elements
Contested	• Source of elevated pre-development nutrients • Water quality targets where elevated pre-development nutrients occur
Unknown	• Spatial distribution of wetlands and elevated pre-development nutrients • Level of risk of organic nutrient forms on receptors

Figure 18 Post development water resources: pre-development nutrients state of knowledge

3.2.3 Acid Sulfate Soils

Acid sulfate soils form when soils naturally containing sulfide minerals are oxidised, forming sulfuric acid. Oxidation can occur when soils are exposed to the air following excavation or draining, or by the lowering of water table levels. In areas of high groundwater, urban development activities which may disturb acid sulfate soils include estate and underground infrastructure development (including the installation of sewage pipework and pump station infrastructure), construction at depths at and beyond the standing water table, developments involving disturbance to wetlands, lakes and waterways, dewatering operations (including those of minor scale), compacting saturated soils or sediments, drainage works, groundwater pumping, artificial deepening of lakes, waterways and wetlands, de-sludging or otherwise cleaning open drains, displacing previously saturated sediment resulting in groundwater extrusion and aeration of ASS (Department of Environment Regulation, 2015).

A number of practitioners also noted that underground structures, such as retaining walls, may also impede the natural flow of groundwater resulting in increased upstream water levels and decreased downstream water levels - leading to the potential exposure of acid sulfate soils.

Resulting acid can release other substances, including heavy metals, from the soil and into the surrounding environment leading to range of environmental consequences including (Degens, 2009); (Department of Water, 2012); (Queensland Government, 2016):

- Soil, waterway and wetland acidification.
- Reduction of soil stability and fertility.
- Degradation of wetlands, water dependent ecosystems and ecosystem services.
- Loss of habitat ecosystem complexity and biodiversity through impacts such as fish kills, harm to other aquatic organisms and vegetation deaths.

Acid sulfate soils are widespread around coastal areas of Australia. Prior to 2000, acid sulfate soils were not identified as a significant issue in the greater Perth region (Water and Rivers Commission and Department of

Environmental Protection, 2002); (Degens, 2009). Subsequent acid sulfate soil planning policy development for Western Australia identified particular areas of concern, including areas with high water tables on the Swan Coastal Plain (areas where the highest known water table level is within three metres of the surface) (Department of Water, 2012).

Acid sulfate soil risk mapping of the Swan Coastal Plain (and other parts of Australia) is required by practitioners as a screening tool to assess the level of risk of acid sulfate soils for broad scale planning purposes. Further site-specific investigations are then required to determine if acid sulfate soils are actually present and whether they may pose a risk to the environment.

For areas of particular concern of acid sulfate soils occurrence, detailed site investigations and the preparation of acid sulfate soil management plans may be required as part of special planning controls or approvals in relation to development area or site works. There are currently no requirements for detailed site investigations and acid sulfate soil management plans for the purpose of long term management of groundwater levels in areas of high risk of acid sulfate soils.

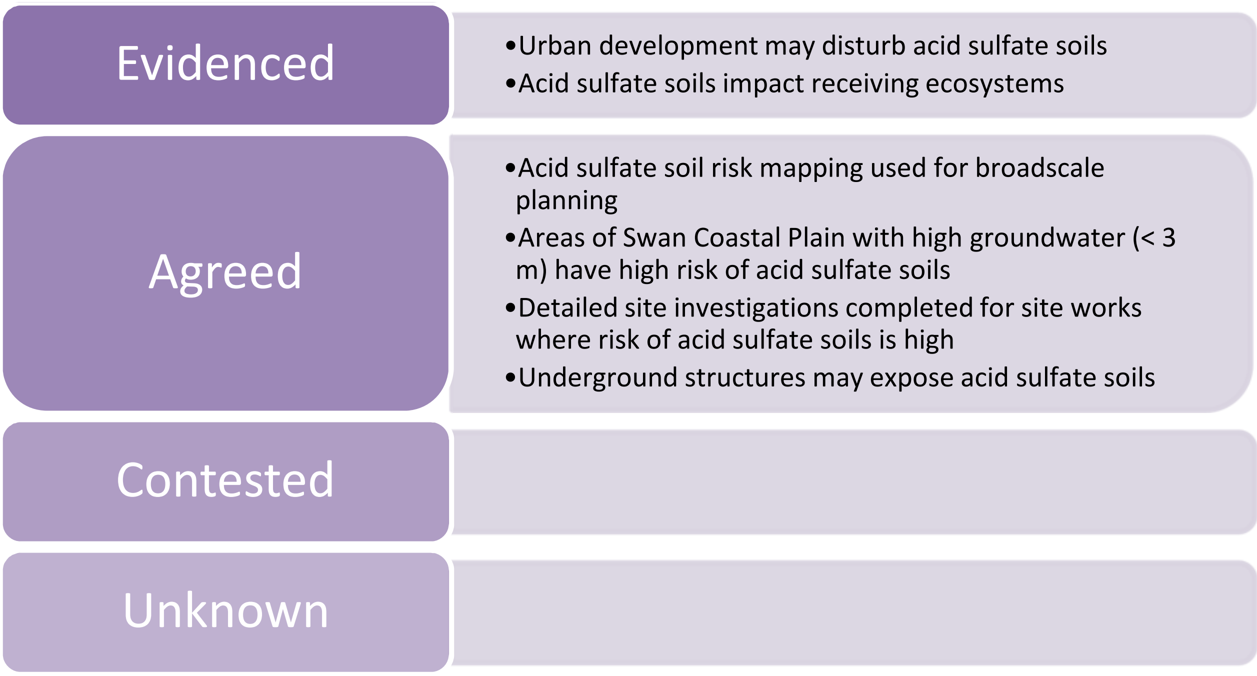

Figure 19 Post development water resources: acid sulfate soils state of knowledge

3.3 Management measures

3.3.1 Measures to maintain pre-development water balance

Decreases in groundwater recharge and subsequent increases in surface water runoff are frequently managed through the use of infiltration measures, including:

- Surface infiltration devices such as basins or swales.
- Underground infiltration devices such as tanks and soakwells.
- Disconnecting impervious surface or creating ICIA's.

As discussed in Chapter 3.1.7, the effectiveness of such devices is subject to a number of variables and uncertainties related to runoff generation and aquifer characteristics.

3.3.2 Vegetation to control groundwater levels

Vegetation used to control groundwater levels is well researched in agricultural areas for salinity control. In the presence of trees, Carter et al. (2010) report that a plantation of trees can be more effective than a pump in maintaining a deep water table and thereby controlling waterlogging and associated salinity. Whilst there is sufficient evidence on the effect of plantations and forests on groundwater levels, there is less evidence in urban settings, where there is a variety of species, and complicated spatial land use distributions associated with roads, public open space and gardens. Further discussion is provided in Chapter 4.3.8.

3.3.3 Water Dependant Ecosystems water regime

Maintenance of the pre-development water balance is important to protect the ecological values and ecosystem functions of water dependent ecosystems (WDE). Where a high value, water dependent, ecosystem may be impacted by a change in land use to urban development, practitioners are generally required to identify the level of risk to WDEs.

For urban development within Western Australia, practitioners are required to maintain or improve pre-development conditions, or where changes to pre-development conditions will occur they must demonstrate that the changes will not result in unacceptable adverse effects on WDEs (Department of Water, 2013b). For WDEs with defined high ecological values, the sensitivity of the ecosystem to changes in site water balance may need to be defined through site specific assessments, and determinations of the ecological water requirements or site water balance.

Western Australian planning guidance notes that proposals for planning scheme amendment for urban use should include an assessment of approaches to form land modification (e.g. cut to fill, filling) that reduce impacts on WDEs (Western Australian Planning Commission, 2008).

Adaptive management of urban drainage may be implemented to manage or improve environmental outcomes. For example, drainage infrastructure constructed in the 1990s to enable urban development of the groundwater constrained South Jandakot region of Perth diverted drainage water away from the Beeliar wetlands. Following rainfall decline in the southwest of Australia and reduced wetland water levels, key stakeholders initiated a water supplementation program to protect the Ramsar listed Thomsons Lake, supported by an appropriate monitoring regime (Department of Conservation and Land Management , 2006).

Buffers may be used to minimise risks associated with human disturbance in the vicinity of a WDE. A hydrological buffer means that potential impacts to water regimes due to drainage design and groundwater controls are not permitted within the buffer zone, although development can occur within the buffer (Department of Water, 2010 b). Ecological buffers generally mean that no disturbance or development is allowed within the buffer zone.

Special planning controls or conditions may also accompany local planning policy where planning applications may present a risk to a WDE or receiving waterbody. For example, the City of Swan Local Planning Scheme 17 identifies special conditions in response to the environmental attributes and values of different development areas. For the Albion development zone (including the potential Brabham development area), the Special Use conditions specify the preparation of a range of management plans to protect significant environmental features, including Wetland Management Plans, Bushland Management Plans and Threatened Ecological Community Management Plans.

Internationally, the Florida Springs Task Force (established in 1999) developed a range of strategies and action steps to protect and restore Florida’s springs. These included outreach (community education), information (monitoring programs, research), management (coordinated land use planning, best management practices, acquisition of land), regulation (legal protection of water sources and values) and funding strategies (Florida Springs Task Force, 2000). Action steps to achieve the strategies are reported to include the development of protocols for spring protection during revision of land use zoning, the identification of vulnerable spring recharge areas and provision of enhanced protection of groundwater aquifers under existing Florida legislature including Strategic Regional Policy Plans.

3.3.4 Measures to capture or treat pollutants

An important aspect of water sensitive urban design (WSUD) is applying best practice management measures to capture and treat pollutants. Best practice management measures include structural and non-structural controls, with practitioners typically implementing these in a treatment train targeted at the pollutants of concern at different stages of the design (Figure 20).

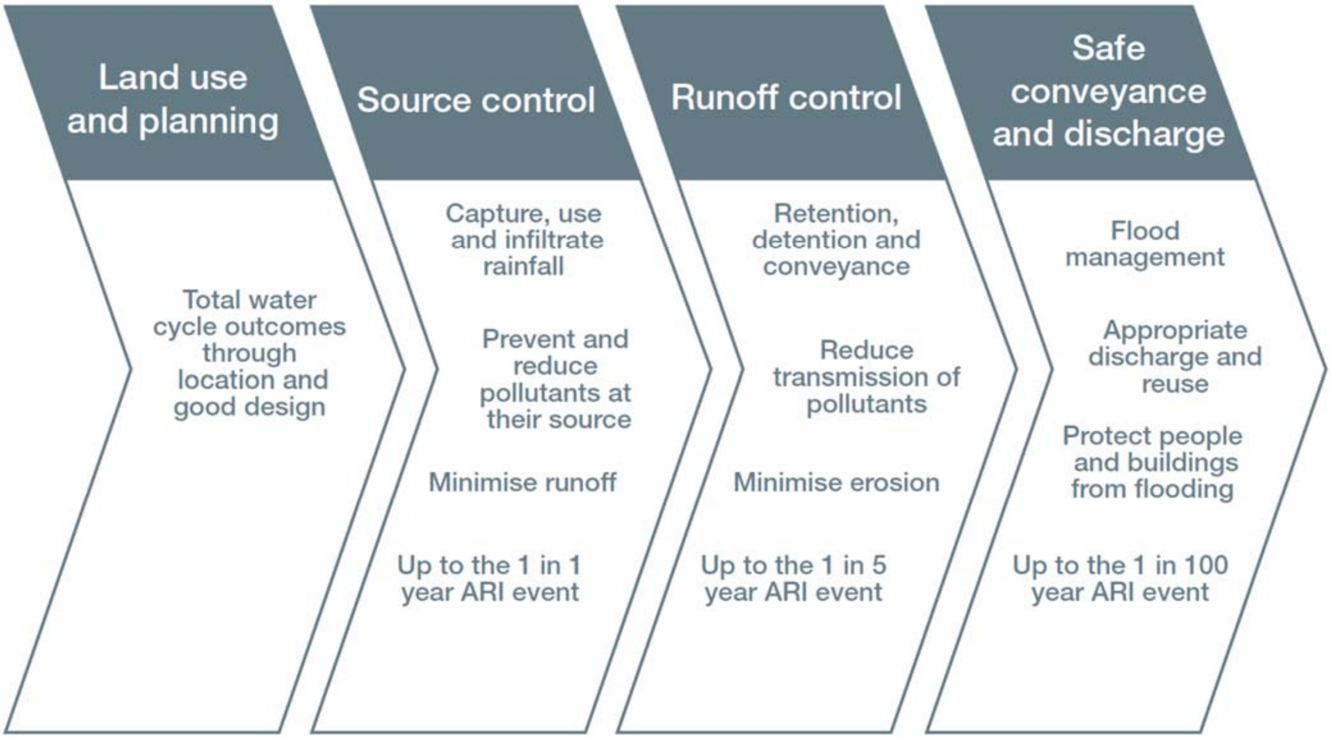

Figure 20 Water sensitive urban design treatment train (Department of Water, 2011)

Structural controls are engineered devices implemented to manage stormwater drainage quality and quantity, while non-structural controls are institutional practices designed to prevent or minimise pollutants from entering stormwater drainage (Department of Water, WA, 2009). Source control is identified as the most effective means of reducing pollutant export from a development area, based on the premise that it is easier to control pollution at the source rather than treating it within the drainage system (ARMCANZ and ANZECC, 2000).

Barron et al. (2010) reviewed the most effective WSUD elements to target nutrient forms in Perth urban drains that intercept shallow groundwater. They note that there are limited options for in-situ groundwater treatment and organic nutrient forms, and while no single WSUD element will treat all nutrient forms, vegetated elements are more effective in nutrient control than non-vegetated elements. Key recommendations were for non-structural controls that prevent nutrient input (fertiliser control, soil amendment) and structural water quality control measures (lining of infiltration elements with soil amendment, bioretention systems, drain maintenance) that remove nutrients from the conveyed waters.

The Urban Nutrient Decision Outcomes (UNDO) tool (Department of Water, 2016) was developed to evaluate the nutrient reductions that could be achieved by the conceptual design of structural WSUD elements for urban development in Western Australia. It is intended to be used at the planning stage of development to assist developers to select best practice WSUD elements based on nutrient export rates and structural WSUD element efficacy based on local data (Department of Water, 2016). UNDO does not consider pre-development (or legacy nutrients), identifying that elevated nutrient concentrations in groundwater may need to be managed concurrently (Department of Water, 2016). Elsewhere in Australia, the MUSIC modelling tool (eWater, November 2013) is widely used for such purposes.

A key regulatory concern is the lack of validation of the efficacy of structural controls, such as bioretention WSUD elements, within high groundwater environments (Department of Water, 2010a); (Ocampo, et al., 2017), and (Hunt, et al., 2017). Practitioners are also uncertain of the effectiveness of WSUD elements in areas of high groundwater, with some Western Australian practitioners noting that the water quality performance of bioretention elements was reduced due to interaction with groundwater, while others noted that with shallow groundwater being the predominant nutrient source, that unlined WSUD elements were designed to enable treatment of intercepted groundwater. Guidelines have recently been prepared to assist the development of monitoring programs to assess the performance of WSUD elements in areas of high groundwater (Hunt, et al., 2017).

Ocampo et al. (2017) assessed the performance of two biofilters (a raingarden and a bioretention basin) in areas that experience seasonally high groundwater on the Swan Coastal Plain, finding that both the hydrological performance and nutrient attenuation were impacted. Based on the key findings, the study recommended that a treatment train approach should be applied across a catchment that provides a range of redox conditions (i.e. alternating surface and subsurface elements), is designed to extend subsurface travel times through filter media and considers placement of biofilters spatially across the catchment (including upland areas as a means of source control) to increase infiltration, subsurface travel times and nutrient attenuation. The importance of dissolved oxygen dynamics/redox conditions on nitrogen concentrations in shallow groundwater beneath infiltration type WSUD elements (trench, basin, bioretention, raingarden and swale) has also been identified in several local (Appleyard, 1993) and international studies (Fischer, et al., 2003); (Datry, et al., 2004); (O'Reilly, et al., 2012).

Over the last two decades, there has been a concerted effort to restore urban streams around the world, particularly in new urban developments. These works aim to mimic pre-development conditions, slow stormflows, reinstate ecosystem functionality and improve amenity for residents (McGrane, 2016). Riparian zone management and the re-engineering of urban drains into living streams have also been undertaken for nutrient removal purposes. The nutrient retention effectiveness of these engineered systems, particularly in areas with high groundwater levels, remains unclear due to changes in the complex subsurface hydrology under urbanisation that in most cases changes the depth to the water table and affects groundwater quality (Groffman, et al., 2002).

Critical environmental conditions in the subsoil environment such as soil moisture content, dissolved oxygen (DO) concentrations, pH conditions and oxidation-reduction potentials, are controls on nutrient fluxes through the unsaturated zone. Short travel times can result from water moving through soils with high hydraulic conductivity or macropores, and do not allow sufficient time for nutrient interaction with the soil matrix and may constrain biologically mediated processes in the unsaturated zone. This can also lead to shallow groundwater contamination.

While groundwater interception/contribution to WSUD elements is acknowledged amongst practitioners, the design of these systems is typically targeted at inorganic nutrient species. The dominance of organic nutrient forms in some high groundwater areas (Chapter 3.2.2) may compromise the nutrient removal performance of a typical bioretention WSUD element designed to treat inorganic nutrient species (Barron, et al., 2010); (Ocampo & Oldham, 2013).

Key practitioner comments around the design of WSUD elements included:

- Maintaining a balance between nutrient adsorption of soil amendment materials and required permeability of the media (e.g. fill or infiltration media) used in WSUD elements is an issue.

- Flat topography in areas of shallow groundwater is a key constraint to the effective design of biofilter WSUD elements.

- National guidelines (Payne, et al., October 2015) are used to inform biofilter design where there is sufficient head, however many biofilters installed in areas of shallow groundwater don't have adequate clearance from groundwater to provide appropriate treatment.

- Typically economics are a key driver in biofilter design. Where specified biofilter media (e.g. FAWB) is used, this has cost implications which may impact other parts of the development (e.g. POS amenity).

- Some local practitioners have a preference for the design of unlined bioretention basins underlain with subsoil drainage.

- WSUD element maintenance by local government is an emerging issue. Operations and maintenance issues can constrain implementation.

- Better standards of construction and a more consistent language around what constitutes a biofilter is required.

- One interstate practitioner noted that requirements for WSUD elements for small developments (>6 lots) has created piecemeal devices with associated regional management issues, with another noting that large projects can be more cost-effective than small projects.

- Nationally the integration of coastal tidal exchange into WSUD treatment trains is encouraged in some areas, however practitioners have noted vegetation deaths due to tidal inundation.

There was strong agreement from practitioners in Western Australia that the design of WSUD elements is typically driven by local government maintenance requirements or particular design preferences, and not specific water quality outcomes. Concern was expressed that in some instances, the WSUD element design specified in the urban water management plan supporting a subdivision was different to the final constructed element due to subsequent changes to the design during construction at the request of local government. Further, it was noted that the treatment media or soil amendments specified for use in accordance with guidelines e.g. (FAWB, June 2009) may not be installed during construction/landscaping due to local availability or cost implications.

Design of WSUD elements is typically driven by local government maintenance requirements or particular design preference and not water quality outcomes.

Soil amendments are typically used to treat pollutants at source, through improvement of a soil or media's nutrient retention ability. Work completed by the Chemical Centre and Department of Agriculture in the 1980's and 1990's identified that a lack of iron/aluminium hydroxide minerals in the sandy soils of the Swan Coastal Plain was largely responsible for their poor phosphate adsorption (Allen, et al., 2001). After this research, many local governments and approving authorities recommended that sandy soils be amended or blended with clays or loams to improve their phosphate adsorption capacity (i.e. phosphorus retention index (PRI), (Allen & Jeffery, 1991)).

Some examples of soil amendment materials for phosphate retention that are used in Western Australia include sands high in iron (e.g. yellow Spearwood sands), calcareous or lime-rich sands (e.g. Karrakatta soils), brown loams (foothill slope soils which may be blended with sands), and Iron Man Gypsum (IMG), previously known as neutralised used acid (Wendling & Douglas, 2009); (Wendling, et al., 2009). Assessment of IMG under controlled laboratory conditions (Wendling, et al., 2010)) identified its potential use for removing dissolved phosphorus and organic nitrogen in surface water, and has been demonstrated to achieve similar improvements in water quality in trials under field conditions (Douglas Partners, 2012); (Degens & Shackleton, 2016).The longest monitored trial to date has shown reductions in phosphate and dissolved organic nitrogen concentrations sustained over more than 4 years (pers.comm. B Degens 2018). Importation of sand fill to provide groundwater separation is also identified as a water quality buffer, with the fill providing some adsorption of phosphorus. Few soil amendment options for targeting nitrogen species are reported.

Nationally, Moreton Bay Regional Council requires testing of all biofilter media to ensure it complies with required nutrient retention and permeability specifications, a practice which is not consistent across all local governments. This is identified as a subject of contention as there are limited market providers, resulting in potential monopoly pricing.

Groundwater controls installed at or close to the pre-development maximum groundwater level are generally considered to minimise the drainage of shallow groundwater and associated pre-development nutrients to a brief period corresponding with seasonal high groundwater tables, reducing the risk to receiving water sources and sensitive ecosystems. However, this is contested due to the potential for increased recharge following urban development, and requires further investigation.

Where groundwater is controlled at a site, regulatory guidance typically recommends the installation of bioretention WSUD elements with soil amendment at subsoil drain outlets to provide water quality treatment prior to conveyance from the site. Practitioners noted that the integration of water quality treatment where groundwater is controlled is difficult due to the generally flat topography of these areas. More recent approaches have recommended lining of subsoil drainage with a soil amendment targeted at the pollutant of concern (Degens & Shackleton, 2016), (The Civil Group, 2015); (Calibre, 2017), particularly where groundwater control is proposed within an area with pre-existing water quality concerns (e.g. elevated pre-development nutrients).

Planning controls are a key non-structural practice to manage the risk of pollutants in areas of high groundwater. It was noted that state planning policies for urban development should take a risk-based approach with regard to management requirements depending on the local conditions. One interstate practitioner noted that the concept of Neutral or Beneficial Impact (NORBI) was a key management requirement for any development that may affect key groundwater resources.

While it is agreed that non-structural practices are key elements for the management of nutrient and pollutants associated with urban development, the effectiveness of community education and awareness programs to achieve behaviour changes is uncertain. Engagement fatigue is identified as a potential issue and there is uncertainty regarding uptake rate and effectiveness of programs (Department of Water, 2010 b). However, driving attitudinal change is identified as an ongoing process with one practitioner noting that you ‘can’t do it for a while then drop it without the benefits deteriorating’.

Policy provisions implemented by Local Governments may provide a more effective means of delivering outcomes through Environmental Planning Policy, Public Open Space and Landscaping Policy, or requirement for site specific Nutrient Management Plans for areas of concern.

Provision of residential landscaping packages by developers can ensure that appropriate soil amendments are used to target residential gardens, or alternatively they could include native gardens and minimum lawn allocation to reduce nutrient application requirements for gardens and lawns. Based on the UNDO tool Residential Factsheet, the nutrient input rates for native gardens in small residential lots (400-500 m2) is 28 kg/ha/year for nitrogen and 0.9 kg/ha/year for phosphorus, compared to 384 kg/ha/year and 115 kg/ha/year for traditional garden areas (Department of Water, 2016).

It has been suggested that reducing urban lot sizes, and consequently the area of garden established within each lot, will reduce householder fertiliser application and nutrient export on a lot basis (Bowman Bishaw Gorham , 2002); (Kelsey, et al., 2010). This has broad agreement from practitioners, with comments including:

> *"The denser the urban development (smaller lots, less gardens)...better from a water quality perspective as there is less opportunity for fertilisation"*

3.3.5 Acid sulfate soils

As noted in Chapter 3.2.3 detailed site investigations and preparation of acid sulfate soil management plans may be required to manage risks in areas of particular concern of acid sulfate soils occurrence. These requirements typically relate only in relation to development proposals or site works and there is currently no requirement for detailed site investigations and acid sulfate soil management plans for the purpose of long term management of groundwater levels in areas of high risk of acid sulfate soils.

Special planning controls or conditions may also accompany local planning policy in response to the environmental attributes and values of different development areas (as per Chapter 3.3.3). Examples include the City of Swan Local Planning Scheme 17 Special Use conditions for the Albion development area (including the proposed Brabham development). Avoiding the disturbance of acid sulfate soils through the preservation of the soil structure and hydrologic regime is the preferred strategy to minimise potential impacts (Department of Water, 2012), however this may compromise developable land. Where acid sulfate soils are identified, detailed site investigations should be completed to determine the extent of affected land and the most appropriate management strategy for a site.

Alternative management options may include:

- Strategic reburial.
- Stable containment.
- Direct neutralisation.

Evidenced	•Source control most effective management measure •WSUD element design targets pollutants in surface water
Agreed	•Local government preference impacts WSUD element design •Smaller lot sizes reduce nutrient input
Contested	•Effectiveness of WSUD elements in high groundwater •WSUD element design targets pollutants in groundwater •Groundwater control at pre-development maximum groundwater level reduces interception of pollutants
Unknown	•Impact of WSUD elements on subsurface hydrology and nutrient cycling •Nutrient retention effectiveness of living streams

Figure 21 Post development water resources: management measures state of knowledge

4 Impacts of high groundwater on infrastructure

4.1 Water balance

4.1.1 Buildings

Groundwater table rise may cause several impacts on infrastructure and buildings. Among those are the following (Abu-Rizaiza, 1999):

- A reduction of soil bearing capacities. This may result in considerable differential settlement in buildings and consequently cracks in columns, beams, and walls;
- When parts of buildings or bridges lie below the groundwater table or even within its capillary fringe, the strength of concrete and masonry may be impaired due to exposure to polluted groundwater. During wet periods, the structures are exposed to moisture, while during dry periods evaporation creates salt crystals that can exert pressure within the pores of the masonry units or the joining mortar. The salt crystals dissolve during humid periods and recrystallize upon subsequent drying. Repeated cycles of wetting and drying can eventually cause cracking and concrete disintegration.

Lowering of initial groundwater levels may cause subsidence of various scales that may affect utility pipes, roads and basements. This effect can take place not only during dewatering and construction but also in the long-term, as a result of the construction of underground structures which can act as drains or barriers (Marinos & Kavvadas, 1998).

4.1.2 Roads

When the a road is constructed below the ground water level, the bath structures and the pavements are the two most significant road structures that may be influenced by the design water level (Dawson, 2008). Design of these structures requires the determination of maximum groundwater table (or Design Groundwater Levels).

4.1.2.1 Bath structures

Bath structures are concrete structures used to protect pavement and infrastructure where road design intercepts natural groundwater levels and environmental consideration prevent permanent lowering of groundwater. Groundwater level influences the length and height of the side retaining walls to the bath structures and in turn the height of earth batters. The risk of the water level exceeding the design water level may lead to water seeping from the earth batters and over-topping the walls - leading to immersion of the pavement.

The bath structures will need to be reinforced to control leakage which may occur in the event of a failure of the waterproof membrane. Design water levels will impact the height of the structures that require reinforcement.

4.1.2.2 Pavement structures

The immersion of asphalt pavement in water during even short periods of seasonal groundwater level rise can lead to saturation, risk of bitumen stripping (loss of bitumen from the asphalt mix), consequent loss of strength and eventual pavement failure. As the stripping is likely to occur in the lower layers of the pavement, total reconstruction would be required to rectify the problem.

According to McRobert and Foley (1999) around 230 km of main roads and many more kilometres of local roads in the southwest of Western Australia were damaged because seasonal or long-term groundwater level rise was not correctly accounted for in the road design.

Alternative pavements such as concrete and water bound macadam pavements can tolerate immersion, but at a considerably higher cost than traditional pavements. The decision whether to use traditional or alternative pavements is largely based on if water levels are expected to create a risk of pavement saturation.

4.1.3 Utilities

During the construction of utilities, open trenches that intercept groundwater require dewatering. Without management measures, dewatering has the potential to generate numerous impacts both locally and to the receiving environment.

Underground gas, water, electricity and telecommunications infrastructure is largely inconsequential to high groundwater environments during the operational phase, unless excavations are required. Above ground electrical infrastructure (e.g. service pillars, LV frames, HV switchgear) usually requires a 300 mm to 500 mm freeboard above the 1:100 Annual Exceedance Probability (AEP) surface water flood level, and a 500 mm vertical separation to groundwater in the case of substations (Western Power, 2013).

As discussed in Chapter 3.1.3, high groundwater has the potential to infiltrate into sewer systems, increasing loads on sewage treatment plants.

Evidenced	• High groundwater levels reduce structural bearing capacity and can weaken and damage pavements
Agreed	• High groundwater impacts utility construction methods • High groundwater has negligible impact on most utilities in the long term • High groundwater can infiltrate into sewer systems • High groundwater requires special measures for electrical substations
Contested	
Unknown	

Figure 22 Post development infrastructure: water balance state of knowledge

4.2 Water quality

Australian Standard AS2159 identifies that site investigations should test soil and groundwater for aggressive agents that may impact the durability of footings and foundations. The aggressive agents that are targeted include sulfate, pH and chloride.

4.2.1 ASS

Disturbance of acid sulfate soils, and the subsequent potential for soil and water acidification, can lead to a range of infrastructure impacts (Queensland Government, 2016); (Department of Water, 2012):

- Risk of long term infrastructure damage (e.g. culverts, bridge structures, underground structures) through acidic water corroding concrete and steel structures.
- Blistering and cracking of asphalt surfaces, damaging roads and foundations.

- Blocking of reticulation systems, small pipe systems and subsoil drains with iron precipitates and calcium salts.
- Costs associated with maintenance of affected infrastructure.

Areas with high water tables on the Swan Coastal Plain are identified as of particular concern for acid sulfate soils within Western Australia (Department of Water, 2012) . Therefore, the management of proposed urban development in these areas requires detailed investigations to determine appropriate management strategies.

4.2.2 Salinity

Where high salt concentrations are identified in the soil profile under pre-development conditions, there is potential for urban salinity hazard to develop because of rising groundwater. Land development and land use practices in an urban environment that have the potential to contribute to urban salinity include the removal of deep rooted vegetation, changes to landform that alter site drainage, siting of infrastructure and services (e.g. retaining walls), changes to local recharge patterns and the importation of salt in water applied at a site (e.g. with grey water).

The risk of urban salinity may also result from capillary action of soils drawing salt to the surface, and as such the importation of clean fill over saline areas may not be an effective long term solution (Cement, Concrete and Aggregates Australia , 2005).

Localised dryland salinity is reported to be evident on the Swan Coastal Plain wherever a shallow water table coincides with clay-dominated sediments (Smith & Shams, 200).

As noted previously (Chapter 3.2.1), potential sea water intrusion and water quality deterioration may occur where groundwater abstraction results in major changes to the hydraulic head distribution within an aquifer. The effect of saline intrusion is quasi-irreversible, with salinity diffused into pore-water taking decades or longer to elute (Foster, et al., 1998).

Key impacts associated with urban salinity include financial costs from damage to, and shortened lifespan, of buildings and other concrete structures (retaining walls, paths, driveways), as well as additional maintenance of underground infrastructure and services (stormwater and sewerage systems, underground gas and power) and other infrastructure such as roads, bridges, railways, power poles and water storages. Salinity impact on infrastructure can occur as a result of both chemical and physical damage, with the extent of the impact dependent on the concentrations and particular types of salts present, and the composition of the building material (Department of Environment and Climate Change NSW, 2008).

Within Western Australia, the impact of urban salinity has largely been confined to rural townsites and associated infrastructure, with the State Government implementing a program to manage townsite salinity in 1997 (Rural Towns Program) involving 38 towns and communities during the mid 2000s (Commonwealth of Australia , 2006). Impacts of salinity on road assets in south western Western Australia have been reported (McRobert & Foley, 1999). Dames and Moore (2001) report that the damage to housing from townsite salinity was relative to both the depth of the water table and the type of construction, with no economic costs incurred with water table depths of greater than 1.5m. Where saline water tables were within 0.5m of the ground surface, brick houses were reported to have escalated maintenance and drainage repair costs when compared to houses elevated on stumps (Dames and Moore , 2001).

4.2.3 NOx

In locations where there is infiltration of water with high nitrate concentrations coincident with poorly buffered soils and shallow aquifers, there is the potential for nitrate reduction and coupled oxidation of sulfides (Department of Water (WA), 2011). This may result in acidification of the shallow aquifer and associated problems with metal mobilisation and damage to buried infrastructure etc (Chapter 3.2.3).

Evidenced	• Acid sulfate soils and salinity impact on infrastructure
Agreed	• Detailed site investigations completed to quantify risk from site works where risk of acid sulfate soils is high • High groundwater areas (< 3 m) of Swan Coastal Plain have high risk of acid sulfate soils • Potential for urban salinity to develop where high salt concentrations in soil profile or groundwater • Fill not an effective solution due to capillary action • Some groundwater has high NOx potential
Contested	
Unknown	

Figure 23 Post development infrastructure: water quality state of knowledge

4.3 Management measures

4.3.1 Buildings

Management measures to deal with high groundwater are a requirement of the Building Code of Australia (BCA), and are addressed by Australian Standards. The BCA (2016) specifies that a building is to:

- be constructed to provide resistance to moisture from the outside and moisture rising from the ground
- perform adequately under all reasonably expected design actions; and
- withstand extreme or frequently repeated design action.

where groundwater and rainwater are specified actions.

Australian Standard AS 2870-2011 (SAI 2011) establishes performance requirements and specific designs for common foundation conditions as well as providing guidance on the design of footing systems using engineering principles. Sites are classified into one of seven categories, ranging from Class A “Little or no ground movement” to Class E “Extremely reactive”. In greater Perth markets, Class A sites attract a higher sale price and are preferred for slab-on-ground footings. In areas of high groundwater in the greater Perth region, unmodified sites do not achieve Class A classification without either the importation of fill, the provision of groundwater controls, or a combination of both.

4.3.2 Imported fill

Fill material is a management measure used to:

- Meet BCA requirements using simple foundations.
- Achieve certain AS2870 site classifications.
- Protect road pavements.
- Achieve local requirements for on-site disposal of stormwater (e.g. soakwells).
- Achieve local requirements for separation distances.
- Avoid waterlogging of soils, particularly in POS (Chapter 5.1.1).

- Achieve minimum grades for surface water drainage.

Free draining fill material is required to achieve many of the above objectives, however practitioners report combinations of poorer quality material placed at depth, overlaid by free draining material, can still function efficiently.

4.3.3 Groundwater controls

Groundwater controls are a management measure used to lower or control groundwater levels, to achieve many of the same objectives as imported fill. Groundwater can be drained using either:

- Subsoil drains, such as:
  - Perforated pipes surrounded by aggregate and geotextile, also known as a French drain.
  - Curtain drains, with or without a perforated pipe, finishing at or near surface.
- Open drains, such as swales, channels and ditches.
- Pumping systems, typically using a network of spears, sumps, or other options that are connected to a subsoil drainage network.

Practitioners in Australia provided anecdotal evidence that pumping systems are not used in Australia, except as a temporary measure or for basement sump drainage. They also report that subsoil drainage has been known to fail through blockage or soil variability, however subsoil drains and open drains are a preferred method in Australia. United States practitioners also report using subsoil drainage and open drainage, and pumping, for similar purposes.

4.3.4 Managed Aquifer Recharge

MAR is reported by practitioners in Australia as both a potential groundwater control measure, and an unsuitable groundwater control measure. MAR is not strictly classified by the authors as a management measure for groundwater levels, rather it is the collecting or pumping of subsoil drainage water that is the management measure, for another beneficial use such as MAR. Collecting and pumping groundwater is addressed above in Chapter 4.3.3.

4.3.5 Building materials and construction methods

The preference for thin building slabs appears to be a Perth industry preference, with practitioners from South Australia and the Eastern seaboard reporting the use of piles and other construction methods in areas of high groundwater.

4.3.6 Alternate urban form/land development methods

As with the management of acid sulfate soils (e.g. (Department of Water, 2012) or salinity impacted land (e.g. (Commonwealth of Australia , 2006) avoidance strategies may be applied to minimise potential impacts associated with urban development in groundwater constrained areas. SKM (2007) identify adoption of passive land uses over highly constrained sites (e.g. retention of deep vegetation) to minimise the requirement for any intervention to manage groundwater.

A Federal review of the extent and economic impact of salinity in Australia identified urban planning and regulation as a key concern, finding there was little regard for the long term implications of urban salinity when rezoning land for urban development (Commonwealth of Australia , 2006). Similar concerns may be applied to rezoning of groundwater constrained land due to the potential for wide ranging impacts.

In response to the identification of shallow groundwater conditions in an urban investigation area in the City of Casey, southeast of Melbourne, it was recommended that planning guidelines for the appropriate construction of buildings, roads and services should be followed, and development should avoid land uses and land management activities that could promote or create shallow water table conditions (Planning Casey, 2009).

Similarly, it was identified that highly groundwater constrained areas in Cranbourne West in Victoria may require special planning considerations (SKM, 2007).

4.3.7 Roads

Bath structures and alternative pavements described in Chapter 4.1.2 are a means to protect road infrastructure from the impacts of high groundwater.

4.3.8 Trees

Whilst trees are known to lower groundwater levels through evapotranspiration, and the removal of trees is known to cause groundwater levels to rise, only a small number of practitioners reported the potential for trees to be used as a management measure. Practitioners report challenges with retaining trees and providing fill to achieve minimum groundwater clearance requirements. There are also challenges and unknowns in the temporal and spatial distribution of trees, and how this can impact groundwater levels. For example, new developments are likely to feature immature trees that will be ineffective for groundwater level control. The spatial distribution and density of trees also varies across a development, with more trees likely in POS areas and on the verge. Whether this distribution and density is sufficient for groundwater control is unknown.

“Yes, trees can pump water but we have not seen such an approach here”

Trees are an existing management measure for rising salinity, predominantly in rural towns. A bulletin published by the former Department of Agriculture and Food (2001) asserts that trees planted near roads can be an effective method of preventing the ground beneath the road pavement becoming saturated.

“In the road reserve is actually no room to put trees”

4.3.9 Salinity

Key management measures to reduce the impact of urban salinity include avoidance of development in potential salinity hazard areas. Where development is proposed within areas that have the potential to develop a salinity hazard, management measures are focussed around the following key measures:

- Maintain existing site water balance (evapotranspiration and water levels).
- Avoid disturbance of sensitive soils.
- Retain or maintain native vegetation.
- Implement building controls.

Due to the dynamic nature of salinity, it is recommended that where a site has the potential to develop a salinity hazard, impacts may be reduced through consideration of building design and construction types that are suited to the prevailing conditions (Cement, Concrete and Aggregates Australia , 2005); (Buckland & McGhie, 2005). The Building Code of Australia further requires that construction uses more damage-resistant materials, while Australian Standards (AS2159) identifies concrete and steel classifications under various exposure conditions (acid sulfate soil and salinity) and soil conditions.

The Department of Environment and Climate Change NSW (2008) identifies the use of exposure class bricks, or alternatively using a brick with a low initial salt content, as further precaution in potential salinity hazard areas.

For sites that have existing salinity hazard, or the potential to develop urban salinity, the use of fill may not be an effective long term solution as there is potential for capillary action to draw salts to the surface (Cement, Concrete and Aggregates Australia , 2005).

Buckland and McGhie (2005) identify a wide range of strategies for managing urban salinity in areas where an existing issue is identified.

Evidenced	• Imported fill and groundwater controls are used to achieve multiple objectives • Alternative building methods acheive BCA requirements
Agreed	• Salinity hazard managed through maintining water balance
Contested	• Trees as a groundwater management measure • Planning measures for high groundwater and salinity hazard areas
Unknown	

Figure 24 Post development infrastructure: management measures state of knowledge

5 Impacts of high groundwater on liveability

5.1 Water balance

5.1.1 Disposal methods of stormwater and associated liveability impacts

Disposal of surface water is typically via:

- Underground detention storage, where stormwater is stored underground and slowly released to the downstream stormwater network.
- Underground infiltration storage, where stormwater is infiltrated into a superficial aquifer. Typical products used in Australia include soakwells (Western Australia), infiltration trenches, and infiltration tanks.
- Surface detention storage, where stormwater is stored in a basin and slowly released to the downstream stormwater network.
- Surface infiltration storage, where stormwater is infiltrated into a superficial aquifer via basins, swales, or biofilters.

Other disposal methods, such as MAR and stormwater harvesting, also require temporary storage. MAR is widely used in South Australia and stormwater harvesting is widely used on the Eastern seaboard.

Disposal of stormwater via infiltration and surface flow attenuation affects liveability through:

- Consumption of land for surface-based infiltration measures. Surface based infiltration measures are preferred in areas of high groundwater due to low vertical separation distances favouring such measures. Where vertical separation distances are low, storage depth is constrained, and therefore storage areas are expanded to achieve the target storage volume. Furthermore, low vertical separation also decreases infiltration rates as described in Chapter 2.1.1, therefore increasing storage volumes and required areas.
- Seasonal or event-based waterlogging of soils, either in gardens or Public Open Space due to local and temporal increases in phreatic surface as described in Chapter 3.1.7.
- Seasonal or event-based ponding, exceeding 96-hour durations at certain times of the year (Department of Water (WA), 2011), are a mosquito breeding risk, as well as restricting public access. Extended ponding can have further public amenity risks associated with algal blooms, pests, and odour.
- Flooding, caused by insufficient storage requirements due to the underestimation of post-development groundwater rise.

Disposal of stormwater to groundwater has some benefits to liveability, including:

- Reduced downstream surface water infrastructure and land take, due to lower runoff rates and volumes, particularly open channels and basins.
- Urban heat island mitigation.
- Increased water body and open space amenity (e.g. increased house prices associated with views to restored waterways (Polyakov, et al., 2017).
- Water storage for irrigation through MAR (Chapter 5.1.2).

5.1.2 Managed aquifer recharge

In many jurisdictions Australia wide, potable water resources are highly constrained and increasing in cost. MAR can offer a fit-for-purpose water resource for irrigation and other uses. Practitioners consider MAR to be unsuitable in areas of high groundwater, unless the target aquifer is not the superficial aquifer. MAR is usually considered in WA where there is no groundwater allocation for a development, therefore providing a positive liveability outcome due to the ability to irrigate gardens and/or POS. Whilst MAR has positive liveability outcomes, practitioners cite treatment and approval challenges for pumped injection projects. Costs and risks associated with such projects are ultimately borne by the community.

"Industry should lead direct harvesting and government should lead MAR and recovery"

Evidenced	
Agreed	•MAR has positive impact on liveability
Contested	•High groundwater increases stormwater disposal impacts on liveability
Unknown	

Figure 25 Post development liveability: water balance state of knowledge

5.2 Water quality

5.2.1 ASS, nutrients (midge/mosquito, algal blooms), salinity

Degradation of water quality because of urban development in areas of high groundwater may occur as a result of disturbance and mobilisation of acid sulfate soils, export of nutrients in site drainage and potential development of urban salinity.

Disturbance of acid sulfate soils, and the subsequent potential for soil and water acidification, can lead to a range of human health and amenity impacts (Queensland Government, 2012); (Department of Water, 2012)):

- Increased mosquito breeding due to acidification of waterbodies, which may increase the prevalence of mosquito-borne diseases such as Ross River virus.
- Loss of visual amenity caused by rust coloured stains, scums and slimes from iron precipitates.
- Loss of amenity due to loss of habitat and vegetation deaths as described in Chapter 3.2.3.
- Damage to public infrastructure as described in Chapter 4.2.1.

Urban development in areas of high groundwater may transport excessive nutrients into receiving waterbodies (rivers, wetlands or estuaries) where it can lead to several amenity impacts including:

- Excessive and unbalanced growth of plants and algae (eutrophication), which may also present a direct public health risk and have associated foul smells.

- Potential for increased breeding of mosquito and midges in eutrophic waterbodies, with associated public health risks and nuisance impacts.

Urban salinity has the potential to impact urban amenity through damage and increased repair and maintenance requirements to public infrastructure (e.g. footpaths, playing fields, parks, gardens and trees) as described in Chapter 4.2.2. A decline in the amenity and biodiversity of high value freshwater water dependent ecosystems may result from urban salinity impacts. Further impacts include the potential degradation of the cultural and spiritual values of important heritage sites.

As noted in Chapter 3.2.1, there is also potential for water quality to improve with a change in land use, particularly where the pre-development land use is an intensive animal industry (e.g. piggery or poultry farm) or a contaminated site. Reduced pollutant inputs and/or site remediation will result in positive impacts on liveability, however improvements in water quality may take some time to be realised due to groundwater residence times.

Trees were reported by a few practitioners as a measure to improve groundwater quality. This is supported by Nidzgorski and Hobbie (2016).

Evidenced	•Acidification of waterbodies increases mosquito breeding •Eutrophiciation increases algal blooms and mosquito breeding •Positive impact on liveability through change in land use
Agreed	•ASS, nutrients and salinity associated with high groundwater have negative impacts on liveability
Contested	
Unknown	

Figure 26 Post development liveability: water quality state of knowledge

5.3 Management measures

Management measures for liveability are covered by management measures for water balance and infrastructure, in Chapters 3.3 and 4.3.

6 Summary and conclusion

6.1 Impact and literature review matrix

6.1.1 State of knowledge

Table 1 summarises the state of knowledge of the aspects and impacts addressed in this report.

Table 1 State of knowledge

State of knowledge	Aspect
Evidenced	Pre-development evapotranspiration rates
	Precipitation intensity, duration and temporal patterns
	Pre-development groundwater levels fluctuate seasonally and due to events
	Pre-development land use impacts water quality
	Urbanisation alters vegetation cover, soils and ground cover
	Post-development groundwater levels fluctuate seasonally and due to events
	Potable water used for irrigation adds to groundwater balance
	Potable water leakage adds to groundwater balance
	Impervious surface impacts on water balance in low groundwater environments
	Concentrated infiltration causes local increases in groundwater level
	MAR adds water to the target aquifer water balance
	Urban development impacts water quality
	Urban development has high nutrient load compared to low intensity agriculture.
	Fertiliser is key nitrogen input in sewered urban development
	Pre-development nutrients in Swan Coastal Plain dominated by organic forms
	Acid sulfate soils impact receiving ecosystems
	Source control most effective management measure
	WSUD element design targets nutrients in stormwater
	High groundwater levels reduce structural bearing capacity and weaken and damage pavements
	Acid sulfate soils and salinity impact on infrastructure

	Imported fill and groundwater controls are used to achieve multiple objectives Alternative building methods achieve BCA requirements Acidification of water bodies increases mosquito breeding Eutrophication increases algal blooms and mosquito breeding Positive impact on liveability through change in land use
Agreed	Pre-development infiltration rates Interception rates Water quality monitoring is used to characterise pre-development conditions Water quality monitoring parameters Post-development groundwater levels with groundwater controls Gravity sewer systems remove water from groundwater balance in high groundwater environments Change in water balance impacts WDE water regime Granular fill increases infiltration potential Groundwater controls remove water from groundwater balance Shallow groundwater short-circuits nutrient pathway between source and receptor Groundwater controls reduce groundwater residence time and potential for nutrient attenuation Legacy nutrients impact receiving water quality Elevated pre-development nutrients common where pre-development land use is rural or semi-rural Organic forms difficult to treat using unlined biofiltration WSUD elements Acid sulfate soil risk mapping used for broadscale planning High groundwater areas (< 3 m) of Swan Coastal Plain have high risk of acid sulfate soils Detailed site investigations completed to quantify risk where risk of acid sulfate soils is high Local government preferences impact WSUD element design Smaller lot sizes reduce nutrient input High groundwater impacts utility construction methods

	High groundwater has negligible impact on most utilities in the long term High groundwater can infiltrate into sewer systems High groundwater requires special measures for electrical substations Potential for urban salinity to develop where high salt concentrations in soil profile or groundwater Fill not an effective solution due to capillary action Some groundwater has high NOx potential Salinity hazard managed through maintaining water balance MAR impacts on groundwater levels, flows and quality MAR has positive impact on liveability ASS, nutrients and salinity associated with high groundwater have negative impacts on liveability
Contested	Infiltration rates in high groundwater Lateral flow and fluxes to surface water Fluxes to confined aquifer Evapotranspiration rates in high groundwater Groundwater level monitoring procedures Pre-development groundwater level determination Timeframe to characterise pre-development water quality Post-development evapotranspiration rates Post-development groundwater levels without groundwater controls Post-development recharge rates Methods for predicting post-development groundwater levels Horizontal separation required to reduce impacts Impervious surface impact on water balance in high groundwater environments Runoff coefficients Continuing losses in high groundwater environments Continuing losses in sand fill

	Long term performance and maintenance of subsoil drains Rates of runoff from groundwater controls for different soil types/ lot sizes, etc. Infiltration device infiltration rates Infiltration device blockage rates Rainwater tanks impact on water balance Source of pre-development nutrients Water quality targets where elevated pre-development nutrients occur Effectiveness of WSUD elements in high groundwater WSUD element design considers nutrients in groundwater Groundwater control at pre-development maximum groundwater level reduces interception of pollutants Trees as a groundwater management measure Planning measures for high groundwater and salinity hazard areas High groundwater increases stormwater disposal impacts on liveability
Unknown	Bore placement where subsurface conditions vary Methods for predicting post-development evapotranspiration rates Impact of land form modification Rainwater tanks impact on stormflow Level of risk of organic nutrient forms on receptors is uncertain MAR clogging potential and rates MAR backwash requirements Post development water quality Spatial distribution of wetlands and pre-development nutrients Level of risk of organic nutrient forms on receptors Impact of WSUD elements on subsurface hydrology and nutrient cycling Nutrient retention effectiveness of living streams

6.2 Recommendations and next steps

[To be agreed by steering committee]

6.3 Conclusion

[To be agreed by steering committee]

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Appendices

Appendix 1 Interview Questions

General:

1. What has been your experience working in areas of near-surface groundwater?
   What is your role?

Water Balance

2. How does [stormwater drainage/ vegetation/ impervious surfaces/ soakwells/ rainwater tanks/ imported fill/ climate change] impact site water balance? Please consider surface water flows and volumes and near-surface groundwater levels. What evidence do you have to support this?
   Did you need to assess these impacts? If Yes, what methods did you use?

Water quality:

3. What happens to [nutrients/ other pollutants/ ASS] as a result of development? Consider concentrations, load, species, etc. What evidence do you have to support this?
4. How does [stormwater drainage/ vegetation/ impervious surfaces/ soakwells/ rainwater tanks/ imported fill/ climate change] impact water quality? Please consider surface and near-surface groundwater quality. What evidence do you have to support this?
5. How WSUD treatment elements (e.g. biofilters) perform in high groundwater environments? What evidence do you have to support this?
6. Where WSUD treatment elements (e.g. biofilters) have been incorporated in an urban area with near-surface groundwater conditions have these been constructed and installed in accordance with nationally approved guidelines? (e.g. Adoption Guidelines for Stormwater Biofiltration Systems, Payne et al. 2015).
7. Where WSUD treatment elements have been installed in an urban area with near-surface groundwater conditions, did the design of the WSUD element consider potential interaction with near-surface groundwater? If Yes, how did the design accommodate near-surface groundwater inputs?
8. Where WSUD treatment elements have been installed were any design modifications made due to availability of locally sourced materials or due to local conditions? For example did the treatment media meet FAWB guideline specifications? Were the WSUD treatment elements unlined or lined?
9. Are the methodologies and/or lack of available water quality data impediments for your WSUD projects approval? Please consider surface and near-surface groundwater quality.
   Are there any other issues?

Flood risk:

10. What method do you use to calculate water losses (abstraction) for flood prediction under post-development scenario? Would the method apply under high groundwater conditions? Is there a better method? Is there an industry used method you strongly disagree with?
11. What catchment antecedent moisture conditions are considered for flood risk analysis under post-development scenario? Are water losses considered constant or transient during flood modelling?
12. How many infiltration sources and rates do you consider for flood modelling under post- development scenario?
13. Have you considered the impact of groundwater interaction with stormwater infrastructure for flood prediction under post- development scenario? If Yes, what criteria do you agree and disagree with?

Groundwater levels:

14. How do near-surface groundwater levels change in response to urban development? What evidence do you have to support this?
15. Did you need to estimate this response quantitatively? If Yes, what methods did you use?
16. What measures have you used to control groundwater or increase clearance to groundwater (e.g. subsoil/subsurface drains, open drains, pumping, imported fill)? How does groundwater respond to these measures? What evidence do you have to support this?

17. Which sources of information do you use to define soil profile characteristics and depths and depth to impervious/confining layer for assessment of pre- and post- development groundwater levels? Please provide a few of them with the first being your preferable source.
18. How many sources/types of infiltration processes do you consider in a post- development scenario to assess groundwater levels?
19. What methods and parameters do you use to calculate pre- and post-development groundwater levels?
20. What recharge values do you use to calculate pre- and post-development groundwater levels? Which method do you feel confident with and which do you strongly disagree with? Is there a need for recommended values in areas with high groundwater?
21. Do you think the current approaches to determine pre- and post-development groundwater levels are adequate for their purposes? If yes, what is needed to address this?

Groundwater levels risk:

22. Would you expect groundwater interaction with underground stormwater drainage infrastructure even though measures to increase clearance to groundwater were in place in areas with high groundwater? If Yes, what evidence do you have to support this?
23. Are you required to or have you considered the effect of groundwater interaction on reducing water conveyance of the stormwater infrastructure for different ARI-design flood events? If Yes, which criteria do you use and which one do you disagree with?

Groundwater levels benefit:

24. Other than sustaining groundwater dependent ecosystems in high groundwater areas, do you see benefits to liveability by undertaking a more natural-engineered approach to control high groundwater if innovative built forms allow the development of such environments? Please consider what it would be for winter and summer scenarios for your region.

Groundwater quality:

25. What measures have you used to treat pollutants in near-surface groundwater? How effective was the measure? What evidence do you have to support this?
26. What methods and parameters do you use to calculate pre- and post-development groundwater quality?
27. Are the methodologies and/or lack of available water quality data impediments for your WSUD projects approval? Are there any other issues?

Surface water flows:

28. How do surface water flows change in response to urban development? Please consider changes in flow regime (i.e. stormflow and baseflow). What evidence do you have to support this?
29. What measures have you used to manage surface water flow rates and volumes (e.g. forms of detention or retention storage and/or enhanced infiltration facilities)? How does surface water respond to these measures? What evidence do you have to support this?
30. What methods and parameters do you use to calculate pre- and post-development surface water flows? Do parameters change according to catchment discretization size (e.g. catchment scale dependent)?

Surface water quality:

31. What measures have you used to treat pollutants in surface water? How effective was the measure? What evidence do you have to support this?
32. What methods and parameters do you use to calculate pre- and post-development surface water quality?

Harvesting and Managed Aquifer Recharge

33. Have you considered groundwater harvesting and/or MAR in areas of high groundwater?
34. What are the conditions (e.g. inter-annual variability, site, source, treatment, use, allocation) for successful groundwater harvesting and/or MAR projects in high groundwater environments?

35. Is groundwater harvesting and/or MAR a practical, local-scale solution for management of high groundwater?

Development:

36. Can you identify any alternative building or construction methods that have been implemented in areas of high groundwater?
37. Can you provide examples of building or construction methods/groundwater controls/storage that haven't worked?

General:

38. In your experience working in areas of near-surface groundwater what are the key impediments facing developers and their consultants in getting their WSUD projects approved?
39. What do you think are the key contested areas when undertaking urban development in areas of near-surface groundwater?
40. Who else should we speak with? In particular anyone who disagrees with you?

Appendix 1 Interview Responses

Interview Response One (Helen Brookes)

Name	Helen Brookes
Organisation	Urbaqua Bangor Uni
Interviewer	Andrew Telfer

Question	*Response*
General	
1	Practitioner and reviewer.
Water Balance	
2	All of them impact on site water balance. Degree of drainage and vegetation important at large scale – at small scale the impervious surfaces and soak wells have a larger local impact. See IPWEA report for background – local govt WALGA funded. Only been complete for 12 months – starting to get traction. Development industry has been slow, but most operators are starting to apply principles. Have used all of the methods in that report
Water Quality	
3	Critical are elevated nutrients (nitrogen and/or phosphorus) differs by previous land use (eg piggeries , horticulture etc). Typically, nutrients enter subsurface drains from groundwater and are exported to the surface water system - contamination plumes occur in groundwater. Evidence of nutrient export is sparse, but some post-development monitoring reports on surface and groundwater. North Forrestdale (City of Armadale) starting to provide some evidence of interactions between surface and groundwater systems in exporting nutrient load. Work not yet published, but there are reports from Helen's company with the City of Armadale.
4	Where there is a subsurface drainage system, it is really difficult to integrate a water quality treatment system, without lifting the subsurface drainage to the surface. Some work on treatment in the media surrounding the drains at trial sites (DoWER at Bletchley Park – Brad Degens). Reasonable treatment of stormwater, but the drainage water quality is not as good.
5	Shallow groundwater complicates the WSUD treatment, and where shallow groundwater not considered it compromises their performance. Main considerations in design are whether lined (shallow gw) or unlined (deeper gw), provision or not of a drainage layer, plant selection. Biofilters in WA need a high proportion of dryland planting otherwise irrigation needed. There are a few examples (Wongong Springtime Development – system changed from a retention to detention and treatment strategy – all sw and gw passed through heavily vegetated flow paths)

6	National Guidelines are relevant, but also use the SouthWest vegetation guidelines
7	Discussed in 5. Seperate sw from gw where high nutrient loads, or use gw for treatment system where gw has low nutrient loads.
8	See above
9	Not really. There have been constraints in the past, but people in the approval process becoming more confident. Hands-on approach with approval bodies seems to be beneficial for project carriage. Sometimes time can constrain communication necessary to inform regulators. Lack of available data not necessarily a constraint. Lack of expertise in maintaining systems can be a barrier to adoption by the Councils – how are they managed, who should do this, how frequently, etc.
Flood Risk	
10	Use standard methodologies but different parameterisation. eg in winter flood scenario reduce losses, or in a general assessment use sensitivity testing to compare wet and dry catchment responses. Recharge rates (losses) can be constant or reducing, depending on site and assessment.
11	Depends on system. Using Horton (for eg) sometimes. Catchment specific assessment, matching loss scenarios to assessment of catchment requirements. Can use either constant losses or variable losses.
12	However many are needed. Under development, water-tables generally rise due to implementation of soak wells, and the introduction of fill reduces ET losses. Some sites in sand with an underlying clay layer, other sites with clay to surface. Near-surface materials can change at the hectare scale. Can get localised seasonally perched layers. Some indication from surface geology mapping, but site investigation required to quantify variability.
13	Yes. Definitely. Not necessarily sensible to combine high water table scenario with a major flood event - not particularly common in reality because storm events tend to be summer and high water table events tend to be winter.
Groundwater Level	
14	See 12. Monitoring shows response, modelling shows response, DoW drinking water aquifers assessment supports this. Subsurface drainage system tends to truncate maximum groundwater level but minimum gw level tends to rise.
15	Yes, we need to know the extent it might happen so we can determine the extent of management required on the site. Typically use a site water balance to estimate the scale of change, using a suite of input parameters based on literature review that is applicable to the site conditions. Very occasionally use groundwater models, but usually constrained by lack of data.
16	Generally work in parallel with subdivision engineer. Tend to model groundwater system in cross-section to quantify amount of fill, considering fill provenance, also specify level to set subsurface drains so no impact on

	wetlands etc. Detailed design by subdivision engineer. Subsurface drainage system tends to truncate maximum groundwater level but minimum level tends to rise. Water-tables generally rise due to implementation of soak wells, and the introduction of fill reduces ET losses.
17	Geotechnical investigations, then infiltration testing at a range of locations, or lab testing. Density of investigation depends on client. Geophysics not used, aquifer testing not generally used unless a recharge management strategy is required.
18	Use the ones that are relevant. When using groundwater section, it is broken down into constituent parts (eg verge, soak well) and consider catchment areas and surfaces pertinent to that section, and run through an in-house model based on a spreadsheet analysis.
19	See above
20	Recharge values - biggest area of uncertainty. Can range from 0.5m to 5m/d and probably 90% of samples would fall in this range. Any data is good data. Yes, need to have good science backing up the rates that should be used. However rates are so variable that difficult to prescribe. But could use the range and % as above.
21	Current approaches seem to be adequate for the purpose - there is steady improvement in process and not much need to go to more detail because not enough data to support it. There is a need to stay conservative, but in most instances no longer being overly conservative.
Groundwater Levels risk	
22	Yes. Experience says it still happens. Helen has several sites that are visited regularly and other sites that have needed adjustment post-construction. Groundwater levels usually rise unless there are high levels of groundwater abstraction from the shallow system or from connected deeper aquifer systems.
23	Yes. Consideration of seasonal baseflow generally considered, but generally don't use the high groundwater level for consideration of flood risk. Generally use low groundwater level for design unless there is a high groundwater input, in which case a sensitivity assessment of a range of groundwater levels to determine if there are any potential impacts.
Groundwater Levels Benefits	
24	Can we get away without fill? Depends on nature of built form and importantly the community. Community have expectations of a dry site. Other options require light frame buildings and an acceptance of wet sites by community and industry. Higher level of resistance might be from industry, because industry assumes that that is what the community want. Though the soggy winter backyard issue may be difficult to manage – degree of concern may relate to the size of the back yard – large yard may cope with a small area of soggy, a courtyard can be engineered to cover it up, but in a mid size yard soggy may be unacceptable

Groundwater Quality	
25	N/A
26	N/A
27	N/A
Surface Water Flows	
28	Increases in flow usually occur
29	N/A
30	N/A
Surface Water Quality	
31	N/A
32	N/A
Harvesting and Managed Aquifer recharges	
33	Big potential opportunity that we are not taking advantage of yet. Needs to be progressed as a matter of priority
34	N/A
35	N/A
Development	
36	Foundations – generally thin slab on ground – BCA seem to have dispensation for a 100mm slab on ground, but cost of fill now similar to cost of more substantial footing. Fill can be up to half the cost of development, because of transport costs. Developers starting to consider tradeoffs.
37	N/A
General	
38	There has been a resistance to approval for WSUD, with over-conservative approaches. But now starting to get to a more reasonable and more reasoned approach to fill and WSUD design.
39	Key issue is around maintenance and performance over longer durations – eg 10 years.
40	Local governments in southern outer growth areas - Armadale, Gosnals, Rockingham.

Interview Response Two (Rachelle Gill)

Name	Rachelle Gill
Organisation	Housing Industry Association
Interviewer	Andrew Telfer

Question	*Response*
General	
1	Structural Engineer. Role is to look at housing generally – more involved in the house construction rather than in the development. Broadly represent practitioners at the house construction end. *Discussion on "fill" vs "soggy back yards"* Difficult balance between "soggy back yards" and imported fill. People have expectation that the sites will allow for: masonry construction, pool, level site, backyard will grow grass and not be soggy. Finding right balance between cost and saleability of product is difficult. Perhaps the bespoke part of the market can deal with the "no-fill" scenarios, but not the market appetite to move from fill-based solutions. HIA could perhaps be more innovative – the conversation is happening but alternatives are not getting a lot of traction within the industry. Some examples did not work well which complicates the adaptation process. The market is slow, so risk taking is subdued also. More could be done, but drivers need to be addressed to achieve broad sustainable outcomes.
Water Balance	
2	Haven't looked at water balances at development scale. At local scale, and with stormwater drainage, typical design looks at expected rainfall.
Water Quality	
3-9	HIA are aware of third pipe systems – not aware of anything of any substance yet in WA
Flood Risk, Groundwater Level and Groundwater Levels risk	
10 -23	Rachelle has worked with floods from major water courses, and managing design of buildings and sites subject to flood conditions. There has been no direction from consultants to address higher flood risk in high ground water areas in terms of building design. Standard construction technique is: Footings and slab on ground; double brick skin with outer skin on footings and inner on slab, inner and outer brickwork not tied usually but may be tied in shallow groundwater environments. If there is high groundwater, building footings and foundation designs have to be responsive to site hydrology/hydrogeology,

	Double brick design is deeply ingrained in Perth psyche – framed dwellings not common due to expectation of poor acoustic performance, increased insulation required, lack of skill base for construction. Even where framed, still slab on ground. This preference is reportedly due to a Midland Brick advertising campaign in 50's/60's which did a fabulous job of conditioning the population against framed construction. Buildings need to provide on-site stormwater disposal – sites may need soak wells, which can have different design criteria. Soak wells vary in dimensions from 1800 diameter by 900 deep to 1200 by 1200. Constructed using a precast concrete ring, with geotextile and graded aggregate (road base) in base of hole. Then covered in some fashion. Capacity calculation done by building designer, or by civil engineer in more challenging situations. Size based on storm intensity on impermeable area. As building sites get smaller, which tends to happen at the cheaper end of the market, sizing and spacing constraints mean disposal gets more difficult and designers/builders can run out of space. The solution may be piles and a reinforced foundation to account for decreased bearing pressure of the soil – alternatively modify house design – or adopt new well designs (e.g. cells). Cells are constructed using PVC (or similar) and have lateral as well as vertical recharge. Not a lot of different solutions. Near Swan River (for example) where water table is less than 1 m, addressing on-site stormwater disposal using a cell-based disposal (flatter profile). Also, recent regulation changes relating to overflow from gutters has prompted reconsideration of stormwater gutters etc. More sites are experiencing shallow groundwater issues, and there is an increasing understanding among the builders of the risks and solutions.
Groundwater Levels Benefits	
24	Yes, if the designs and impacts are well considered and informed. The consultants are informed, the builders are becoming aware, but the consumer in general has little knowledge of the opportunities. The risks need to be made clear to consumers and builders. The consumers also have little understanding that "scheme" water is impacting on groundwater levels. In relation to benefits to liveability, while there may be cost efficiency there doesn't appear to be much else that would improve liveability
Groundwater Quality	
25	No comments
26	No comments
27	No comments
Surface Water Flows and Surface Water Quality	
28-32	There is an obligation in the Building Act that any work on a site must not impact on the ability of a site (subject site or adjacent site) to drain surface water and/or groundwater. This has helped raise awareness.

Harvesting and Managed Aquifer recharges	
33-35	Water Corp does recharging at a large scale – not sure if Councils are doing it at smaller scale
Development	
36-37	Non-sandy sites can cause problems if the designs assume that sandy site conditions apply. Small developers/mum and dad developers may not recognise the problem and the need to address it. eg Shire of Kalamunda: the house at the bottom of the grade would smell because of pet faeces entrained in surface water/groundwater due to the poor understanding of how to address ground water over a clay substrate.
General	
38-39	Key contested area is that the risks arising from adverse groundwater conditions, and implications for design, need to be clearly communicated. Regulations specify setbacks etc, but the rationale for the rules are not clearly articulated, so less scope to innovate – an unfortunate by-product of needing to develop regulations. Early disclosure of groundwater risks and design constraints to purchasers would avoid arguments developing later
40	N/A
Summary	
Market has quite fixed expectations regarding building design and private space utility, which need to be shifted. This will take time. HIA are happy to assist with developing capability within the building industry to assist with addressing the issues	

Interview response Three (Joel Hall)

Name	Joel Hall
Date	21/12/2017
Time	3:00-4:30 AEST
Interviewer	Tony McAlister

Question	*Response*
General	
1	Reviewer, researcher and 'partial' practitioner. Developed the UNDO tool/software package.
Water Balance	

2	Major impacts. There is lots of general data around to demonstrate impacts, some of the more process based data are lacking however. Has used an extensive range of modelling tools over the years (MIKE SHE, MUSIC, UNDO and a range of empirical models) to assess water balance change, which does occur! He started modelling initially with more complicated tools, and now feels that we need simpler ('KISS'), but more well informed, tools. This will need better data collection and process conceptualisation before the 'simple' models can be developed. The relationship between UNDO and the near surface groundwater processes in WA is a good example. Joel feels that the CRC could contribute to improving UNDO along the above lines via data collection (e.g. simple fundamentals like how do runoff rates change depending on the key variables of depth to groundwater, soil type and the nature of drainage infrastructure and how do these affect model conceptualisation) and associated process based research
Water Quality	
3	Change markedly, again dependent on depth to groundwater, soil type and the nature of drainage infrastructure. Big issue in a sandy soil based urban development is that runoff that is generated nearly always goes through the soil profile at some stage (via a soakwell, natural infiltration etc) and hits a groundwater table and then a subsoil drain (in high groundwater developments) and subsequently daylights in a drain or enters deeper groundwater, the time for this process can be days-months-years which affects denitrification. Bassendean sands and coffee rocks are an issue in some areas. This process also affects P removal. Biofilters don't work in flat developments common in WA due to head requirements. The big challenge in managing drainage from subsoil drains. Living Streams/Living Waterways are really important opportunities. Also modified soils with high PRI in subsoil drains. Lots of data, needs conceptualisation (see above).
4	See above for much of the discussion which is common.
5	See above re biofilters and head requirements. Source control is a key issue that is lacking attention. UNDO has a (hidden) source control tab. Double surveys for education and source control are required to see how effective this measure actually can be by way of providing cold hard evidence!
6	Payne recommended/used extensively for biofilters where there is sufficient head. There is also a WA Stormwater Manual with good guidelines. Some of these are a little impractical and out of date, could use an update especially with respect to the Living Streams concept. Good discussion around what a drain has to be to achieve water quality improvements……no concrete/lined inverts! Low flow channel has to be vegetated, with pools and riffles, not regularly cleared out by a D9 (as is often the case at the moment in Perth). Suzanne Brown is working with the WA Water Corp to change design guidelines. There is a desperate need for decent monitoring data for a stream that is designed properly. There is plenty of quality monitoring data on most other treatment devices, Living Stream data is a major gap.

7	Yes, this is a common practice in WA. But not always, see (6) – often "biofilters" installed which are regularly inundated with GW, and don't have sufficient clearance to GW to provide appropriate treatment
8	Joel does not work on site and hence had only 'second hand' comments. There is a major issue in WA he felt with using appropriate materials in biofilters, LGA's can be somewhat 'ignorant' of what is required, developers don't import appropriate materials due to cost but often use local 'sand' and 'chuck a few plants in'. This needs addressing. Better standard of construction and a more constant language around what constitutes a "biofilter" (as opposed to a detention basin, infiltration basin or 'rain garden'
9	Yes. Joel feels that there is a burning need for better construction guides, regulatory guides and management goal posts. The methodology is there (UNDO) which is a **tool**, but the **rules** are lacking. A better State Planning Policy (SPP 2.2) is required that takes a risk based consideration of location (e.g. discharging to a coastal site should be different to draining to a sensitive wetland) in terms of management requirements. Joes does not like the generic 80/60/45 (or 80/60/40) load reduction approach. He sees that this is a major impediment for appropriate project approvals.
Flood Risk	
10	Joel has used a range of modelling tools. He has strong views that the best way for post development analyses is with an agreed set of loss parameters (i.e. initial loss, continuing loss and/or coefficient of runoff) for high-groundwater developments in sandy soils. There are too many arguments in the industry with often bizarre complicated designs and numbers that are just not defensible. KISS in this regard. Agree to ROC and initial losses for various land uses (e.g. pervious, roof area connected to a soakwell, impervious connected directly, areas with saturated soils/shallow lakes/palustrine wetlands (e.g. 100% ROC) etc).
11	Same as above, agreed initial and continuing losses required. Would help a lot. Whatever doesn't runoff recharges, this too helps design. There is no comprehensive WA Urban Drainage Manual (like QUDM), which would help.
12	See above, needs definition.
13	There is an issue with the timing relationship between when peak groundwater levels (mid October) and when peak rainfalls typically occur (June-July or in summer), which in WA are offset by several months. Needs to be considered for initial conditions for flood studies. Drain invert levels are also an important consideration, they need to take account of the groundwater level in their placement. Civil Engineers need to talk to groundwater specialists.
Groundwater Level	
14	They pretty much always go up! Depends on the predevelopment land use/condition. There is plenty of evidence around, measurements, reports and lots and lots of modelling. Recharge estimates are a bit sketchy according to Joel, especially as block sizes reduce which are giving more soakwells per ha.

	Better recharge data would help greatly. Recharge data that is applied is often outdated. Research opportunities to better measure recharge (as this is something that government agencies are usually ill-equiped to do).
15	Some material around that is being broadly applied, better data would help.
16	1m of clean fill', soakwells, proper locations of drains, pumping (not a necessarily favoured option). Good discussion that RWT's could add value by reducing recharge through soakwells, Joel said that there is a real need for some contemporary research to discount those who say that RWT's don't make a difference. Feels that there are a lot of 'entrenched' ideas in WA about RWT's that some decent research, contemporary data and pilot/demonstration projects could/may dispel and that they should not be dismissed so rapidly!
17	See above 17. Department of Agriculture has a terrific statewide soils spatial data base. Drilling and site specific chemical analysis is also a common activity. No statewide suitably accurate depth to groundwater map. Joel felt that it would be good to have a better idea of this, even a depth to maximum groundwater level map would help.
18	See above
19	Modelling is commonly used. There are heaps of models. Groundwater atlas helps define pre-development conditions. Post development is via modelling. Where there is >3m existing depth to groundwater defined as no/low risk, where there is <1m existing depth to groundwater is a high risk, the area in the middle is a big unknown and some better guidance would help. Sandy soils only of course. Some developers still use subsoil drains even when the depth to groundwater is >3m. There is potential to save money if there is better data and guidance in this regard.
20	There is a definite need for recommended values in areas of high groundwater – with two big exclamation marks! More measurements are required.
21	If the depth to groundwater is >3m 'yes', if the depth to groundwater is <1m 'yes', if the depth to groundwater is in between these two extremes 'no'. IPWEA methodology for GW level mounding under SS drains is good for transient models but the draft guidelines have issues for the steady-state approach, needs to be updated.
Groundwater Levels risk	
22	A lot of Council engineers still/always think pit and pipes (mainly 'bottomless pits' – which have significant potential for blockage with the accumulation of fines over time), wherein there is a significant degree of actual and potential interaction. Joel feels that there is some potential to reduce this infrastructure if more appropriate infiltration measures are included in a development. The way that subsoil drains work relates to the pit and pipe network, they drain the subsoil drains.
23	Only in terms of drain invert levels and where there are free draining outlets

Groundwater Levels Benefits	
24	Yes! Two big areas of potential benefit. The more naturally engineered a design is - the less nutrient export to sensitive water bodies it will potentially have. Living streams were also discussed, these will have water quality, ecology, urban heating, evapotranspiration benefits etc. Needs quantification and design guidance to advance.
Groundwater Quality	
25	Soil amendments were mentioned. Biofilters were also discussed, they have some measured data. Will only work where there is sufficient grade. SPEL products mentioned, they appear to be expensive - but seem to have potential merit. Wetlands (Leeds (?) Street and Wharf Street) were also discussed. There has been a lot of work done on wetlands, they look like they will work. Potential mosquito issues were discussed. Mosquito policy of free standing water < 3 days in summer can be a barrier.
26	For the pre-development case - there is no 'standard' approach other than data collection. Modelling tools like APSIM could be used, there are lots of legacy issues that make any 'standard' approach problematic. For the post development case – UNDO is widely used. Sharply, Gerritse and O'Campo work mentioned. The time that nitrogen spends in a groundwater system was discussed as being the key to how much denitrification occurs. Darcy type flow equations were used to estimate residence times
27	The methodologies and data are not constraining projects, the issue is the lack of suitable targets. UNDO could be improved in this regard.
Surface Water Flows	
28	Rapid changes between surface and groundwater flow regimes is a key in areas of WA with high groundwater levels. How do surface water flows change in response to urban development – depends on how you 'do' your development, how your 'do' your drainage and the soil type.
29	Discussed earlier.
30	Surface water flows are primarily from sub soil drains. MIKE SHE modelling previously conducted by Joel has confirmed this. CSIRO modelling has also shown that this was the case. Recent Carl Davies and Carlos O'Campo data supports this too. All these data were used in UNDO for post development assessments.
Surface Water Quality	
31	As per 'over east'. Difference in Perth is that there is far less surface water runoff – usually only from impervious surfaces. The road network and associated pit and pipes direct such surface water flows into biofilters.
32	MUSIC effectively used to model the impervious runoff mentioned above, multiple runs conducted to inform UNDO. Swales and bioretention systems are the common BMP

Harvesting and Managed Aquifer recharges	
33	Yes, however regulation and legislation is lacking. Joel's group did the Murray DWMP modelling and also looked at MAR into a deeper, more saline, aquifer. They are moving into Phase 2 studies (PIWI project). Sees a lot of potential in MAR. A lot of 'AR' is already occurring, it's the 'M' that is missing. MAR won't work in high groundwater areas, but in areas where there is a suitable **deeper** aquifer. The Leederville aquifer has significant potential and there is a deeper Gauge aquifer that Joel feels has even more potential in the Murray Region. Departments need to be "system stewards" rather than "blockers" for MAR in the future. SA has a good template
34	See above. Treatment (nutrients, DOC and sediment) is important. The issue is that recharging unconfined high groundwater aquifers may actually make the problems of soil waterlogging worse. This is not the case of confined aquifers or unconfined aquifers that are >3 m below the natural surface level.
35	No
Development	
36	Not really Joel's area of expertise
37	See above
General	
38	Targets, policies and modelling were all discussed as key impediments that could use work
39	Initial and continuing losses from various land uses, runoff coefficients, recharge rates, efficiencies of some BMPs like Living Streams and rainwater tanks, and target methodologies were all discussed
40	No one in particular that we haven't already included in the interview list.

Interview response four (Brendan Berghout)

Name	Brendan Berghout
Date	21/12/17
Time	9:00-9:40 AEST
Interviewer	Tony McAlister

Question	*Response*
General	

1	Practitioner and interested party. Groundwater/hydrologic modelling and water resources background. Key focus of interest is the Tomago groundwater resource at Newcastle and the associated borefield which is a key asset of his organisation. They try and keep urban development away from their borefields.
Water Balance	
2	Urban development and its various management and intervention manifestations all change site water balances in different ways. Most of the work undertaken by this interviewer is regulation driven and predominantly requires first principles assessments of quantity and quality. If a development is proposed that may interact with their assets, they require assessments of water quantity and quality. If they are not happy with what they see, they will object. Their biggest concern is quality
Water Quality	
3	Nutrients and other pollutants increase as a result of urban development. The interviewer has first-hand experience with this in terms of some of the data that has been collected by his organisation. A key issue that was discussed at this stage was the concept of Neutral or Beneficial Impact (NorBI) which is a key management requirement of his organisation for any development that may affect their groundwater resource. Recent experience with PFOS has been a challenge for his organisation, especially in regard to stormwater run-off from RAAF facilities. In short, the interviewer said, ‘people equals contamination’. Also, pathogenic risks associated with stormwater are directly related to travel time through aquifers and short circuiting and this issue needs careful consideration. His key concern were constituents that have a ‘long life’ (pesticides, heavy metals, hydrocarbons). He was not convinced that developments in their catchments are a good idea, even with WSUD.
4	Urban development affects water quality, and his organisation has a good dataset to support this conclusion.
5	The interviewer had no real first-hand knowledge in regard to WSUD treatment elements in high g/w environments. Local government would be the best contact.
6	The interviewer believed that typically MUSIC was used for assessment of WSUD measures, however this was predominantly the remit of local governments such as Newcastle City Council and Port Stephens Council and as such the interviewer was uncertain what current practice was in this regard.
7	No
8	No opinion/not his area of speciality.
9	Yes, fair statement, has some uncertainty about the quality being achieved by WSUD devices, he has more experience with surface water rather than groundwater. He was sceptical about developers delivering ‘high’ quality water from WSUD measures. The long term ‘survival’ of WSUD measures between

	protracted wet and dry climatic conditions was discussed as a key issue of concern.
Flood Risk	
10	No opinion/not his area of speciality. Worried about short circuiting
11	No opinion/not his area of speciality.
12	No opinion/not his area of speciality.
13	No opinion/not his area of speciality.
Groundwater Level	
14	They go up. His organisation has an extensive data set (50-100 boreholes monitored monthly for decades) and lots of ‘first principle’ research. He does not think that the degree of urban development that has occurred in that time has been of a scale that it will have affected their resource to date
15	No, as above does not expect that the magnitude of land use change will have been sufficient to affect their resource.
16	He thought that mounding of urban development pads to manage both flood and groundwater inundation is commonly used in the region. These works are probably managing both influences at various times. Shoal Bay was mentioned as having significant groundwater issues. Talk to Council. Sand mining was discussed, his organisation requires that any sand mining or quarrying development in their area has a ‘floor level’ that is 1m above the highest peak in the groundwater level.
17	No opinion/not his area of speciality.
18	They really only worry about gross landscape infiltration and evapotranspiration with respect to the water balance of their groundwater resource. Any other influences are second order.
19	First principles, mainly data based with some groundwater modelling.
20	This is built into their MODFLOW groundwater modelling
21	Moot point to them, the current and expected scales of development are too small to affect their groundwater resources (apart from the defence forces…
Groundwater Levels risk	
22	Yes, but in their case it is only via surface water drainage channels rather than underground infrastructure. It’s all about the quantity of this interflow and the loss of resource for them! In his remit, there are no specific measures that have been built to increase clearance to groundwater.
23	No opinion/not his area of speciality.
Groundwater Levels Benefits	

24	No opinion/not his area of speciality. There are GDE constraints in and around their operations, but the only real concerns that they have with these areas are in terms of how much water they can extract such that the GDE's are preserved.
Groundwater Quality	
25	They don't do any specific treatment. In terms of management, conventional water quality treatment processes apply at potable water offtakes and they apply HAZOP/catchment risk management approaches to all operations and potential sources of impact on the aquifers.
26	Data collection, when developments do occur (usually industrial) there are usually groundwater management plans required with appropriate planning/monitoring and reporting aspects
27	Decisions are often being made with insufficient data and information and also using a very conservative approach. Hard to use a measured data approach to their situation. Lots of first principles analysis
Surface Water Flows	
28	They increase!
29	Have only one surface water related catchment where they are somewhat worried about this, this is a legacy urban development project that they 'inherited' when a dam was built. This issue is mainly looked after by the local government from a flood perspective, they are worried more about water quality impacts of the development areas. He believes that WSUD is required by the LGA via a DCP processes. A fairly unsatisfactory situation in total.
30	No opinion/not his area of speciality. Local Government requirements.
Surface Water Quality	
31	No surface water treatment by this organisation (as opposed to post dam water treatment which, of course, they do). Drainage infrastructure management is their key concern (e.g. pesticides, dredging too much at one time, etc), they liaise with the LGA in regard to this issue. The organisation has undertaken riparian improvement programs to improve water quality in rivers that run through rural areas, and treats all water that is sourced from surface water sources prior to delivery to customers.
32	No opinion/not his area of speciality
Harvesting and Managed Aquifer recharges	
33	Groundwater harvesting is an inherent part of the organisations business. The organisation has considered MAR, but not in areas of high groundwater levels. Rather, they are looking at it in areas where there are **low** groundwater levels and as such a storage resource that they can use. He felt that if they 'did' MAR in areas of high groundwater that the water would 'pop up' as surface

	water runoff and then be 'wasted'. It is being considered as a drought management measure for the Port Stephens area in the long term.
34	They need enough clearance so that when and if they do MAR it does not pop out as runoff.
35	No, because of the above! Their biggest fluxes to their groundwater resource are rainfall and evaporation and the amount of pumping that they do is second order in this regard. The drivers for groundwater harvesting in this organisation relate to optimisation of the combined use of water from multiple sources to minimise the risk of water shortage, but not to control groundwater levels.
Development	
36	Port Stephens mounding as discussed above.
37	Submerged RWT's discussed as a bad idea in areas of high groundwater as they 'float'.
General	
38	The developers need to demonstrate NorBI wrt groundwater quality and this can be difficult in some situations. There are also less than ideal data on the range of pollutants they are worried about.
39	Lack of knowledge and data on some of the 'exotics' in stormwater, wrt this client it is all about the water quality, not just their concerns but also those of the likes of the EPA, Health Departments etc. Sewer exfiltration and leakage was also mentioned as a potential unknown
40	Port Stephens Council mentioned. Contact to be provided.

Interview response five (Jim Davies)

Name	Jim Davies
Date	15/1/19
Time	1:00-2:00 AEST
Interviewer	Tony McAlister

Question	*Response*
General	
1	Practitioner primarily and in many instances also a reviewer (of other people's/firms work) through his consultancy JDA Consultant Hydrologists based in and focussed on WA. Mainly works for land developers and local governments, usually as a prime consultant. Jim is keen to see wider

	information dissemination to make life easier for everyone, consultants, developers and regulators.
Water Balance	
2	Discussed rainfall rates falling in South West WA and climate change related impacts that have occurred progressively over the last 1-2 decades. This is making the urban water groundwater flood risk issues they are used to dealing with in Perth 'easier'. Highlighted the fundamental difference between dealing with developments overlaying sand and clays on the coastal plain and those further inland on more elevated land. Commercial and industrial land uses were mentioned as needing attention well as residential land use. Do we need to assess these matters – yes! Have to either lower water table and/or import fill to achieve separation between development finished levels and groundwater. JDA do some groundwater modelling, not on every job. Groundwater levels generally rise post development, and as such this is a 'risky business', with there being considerable commercial risk to consultants (over and above environmental impacts/risks). Don't tend to hear of many 'problems' with developments between clients and consultants. Decisions as to when to model and when not to model are subjective. In nearly all cases of risk (groundwater within 2m of the surface) JDA would be recommending the installation of subsoil drainage, in addition to fill. Development reduces evapotranspiration and increases groundwater recharge, particularly into imported sand fill. More vegetation in a Water Sensitive City is beneficial in this regard (urban cooling was also discussed at this time). Specific numerical models are used by Jim's company JDA for the sizing of infiltration basins.
Water Quality	
3-9	DWER UNDO model agreed as industry standard of modelling the impact of urbanisation. Water quality is somewhat less of a concern to Jim than quantity. With the change from agricultural land uses to urban land uses, they can usually predict/show an improvement in water quality, especially if the base land use case is grazing (or even more so horticulture) due to fertilisation practises required for the poor/sandy soils on the Perth coastal plain. The denser the urban development (smaller lots, less gardens) the better from a water quality perspective as there is less opportunity for fertilisation. Water quantity however will be a bigger issue. Imported sand is a water quantity and quality 'buffer'. Sand fill operates/provides a long-time frame (weeks instead of hours) detention role for infiltrated stormwater. Generally, Jim does not feel that bioretention systems have been well applied in WA. If they are configured as infiltration systems, then it's generally OK, but when they are made more like bioretention systems 'over east', with liners and modified soils that create standing water, then there are issues. Jim prefers proper subsoil drainage beneath bio basins so that they empty easily and properly. Discussed Joel Hall comment on the inappropriate use or specification of bioretention media, Jim disagreed. He thought that the market was better than Joel had

	highlighted. JDA use the FAWB specifications for this. What actually gets built though is sometimes an issue between the landscaper and others. The Balance between nutrient adsorption of imported soil media and associated permeability is an issue. Ingress of groundwater into a bioretention system is standard practice in WA. This is what they want to treat…..groundwater can't/shouldn't be excluded as the pollutants are 'in' the shallow groundwater, not in the surface runoff. National standards and publications have not picked up this subtlety! No liners used in WA biobasins according to Jim.
9	Jim does not feel that there is a particular need for more methods or data. He encourages source control and catchment management based approaches (street sweeping was mentioned) and ensuring that pollutants (esp nutrients) are applied at the minimal possible level. Guidelines to new land owners were discussed. Management of bio basins by LGA's was also discussed as an emerging issue. More methods and data won't change the above. Jim reiterated that in his opinion, as lots are getting smaller - water quality is becoming less of an issue. The focus on people asking for more data and more methods he feels implies that there is a growing problem, not one that is actually getting less of concern as time passes. Jim feels that more data and monitoring to confirm his assertion would help. Jim mentioned that most consultants are doing some post development monitoring, more use could be made of the data that are being collected. The CRC could help in this regard.
Flood Risk	
10-13	Jim noted that this is a surface water, not groundwater based, flood risk issue. Conventional approach is to assume initial and continuing losses in software such as the XP suite, or for a rain on grid 2D model. There is no industry standard for these approaches, and Jim felt that some agreement on these losses would greatly assist the industry. This issue is nearly always resolved from first principles and on a case by case basis. The DoW has not taken much interest in this until mid 2017, and then only at officer level rather than policy development. Joel Hall DOW was also discussed from understanding flooding pre-development. The lack of a WA Urban Drainage Manual that is specific on what initial and continuing losses are able to be used was discussed (see Joel Hall meeting notes also). Jim felt that such a document would be of use in WA. Jim had been talking to Greg Claydon (formerly Director DoW) about getting some research initiated (via the CRC WSC) into the issue of initial and continuing loss. The industry has been designing and building development on areas of high groundwater tables for decades, and in Jim's opinion there has been very little, if any, flooding resulting from this. Maybe they have all been too conservative? Flood risk associated with high groundwater is not high on the agenda for the DoW or local authorities, although IPWEA WA may be taking an initiative on this in 2018.
Groundwater Level	

14-21	There is lots of evidence. Post development, generally speaking, groundwater levels will rise - but not always. If a lot of people use their own private bores and if the LGA put bores in, then the groundwater level can actually fall. With more and smaller lots (see above) and less requirements for private bores (due to smaller yards and less irrigation requirements) the groundwater will rise more than usually expected, unless there is appropriate subsoil drainage. Smaller lots can cause less water quality problems but potentially greater water quantity problems. The additional water being infiltrated could be reused (a horticulture project was discussed, and in particular Nambeelup in the Shire of Murray – see http://www.peel.wa.gov.au/mar-study-milestone-for-transform-peel/). Taking extra recharge and conveying that 'away' from new housing estates and using it for a horticultural precinct. This sees the extra water as a positive and a new water resource. Jim is not a big believer in rainwater tanks due to the highly infrequent nature of rain (Perth can go from November to April and not have any rain at all). The intervals between rainfall events in Perth are far greater than over east. Jim feels that in general RWT's give people a warm and fuzzy feeling, but that economically they do not stack up against 'schemed' water.
16	The main method used is sub soil drainage - draining to an open channel which then conveys the water away. Vertical slice groundwater modelling is conducted by JDA to assist in the design of spaced drains, this is a big focus of their office now. Future climate scenarios are also of interest and are being used in this modelling, they use some of Joel Hall's research in this regard. This indicates that the rainfall in WA will continue to decrease and as such the issues with high groundwater tables that have been of concern in Perth should also decrease
17	Local data collection is used, to specify parameters in models and then for imported fill. Data is then used for modelling. Slice modelling between drains (typically 70m spacing) and then monitoring post construction. If the fill is not permeable enough, there may well be problems as the groundwater mounding will be higher as water will not be able to leave/move between the adjacent sub soil drains.
18	Fill hydraulic conductivity (permeability) is a big issue. As people try and minimise fill, this is becoming more and more of a problem. Jim said that there is an issue with the permeability of fill that is available, the more permeable fill is being exhausted. This affects the commercial risk to consultants and contractors. Less about environmental impact and more about problems for private landholders and local authorities.
20-21	JDA use data and experience that they have collected over many years. A lot of this is commercial in confidence and something that they can and should, within reason, protect. Some more logical and appropriate sharing of knowledge and subsequent agreement on standards for development in areas of high groundwater levels would greatly assist the industry
Groundwater Levels risk	

22-23	Definitely yes. Jim mentioned that there is generally no OSD in Perth, underground stormwater drainage can and does interact with the groundwater tables in certain areas. The key to this question is whether or not appropriate analyses have been conducted. Re Q23, 1,10 and 100 yr events discussed.
Groundwater Levels Benefits	
24	Yes. Assuming other than sub soil drainage, Jim feels that revegetation, grassed POS, capture and reuse of water can have a benefit in general.
Groundwater Quality	
25-27	Jim said that their argument in regard to this question is that the importing of a layer of sand fill itself to provide separation from an elevated groundwater table will of itself provide a major water quality 'buffer'. It can 'adsorb' a certain amount of P for example (they have done some modelling which indicates that that could be up to 100 years of infiltration in some cases). N will tend to 'flow through' the soil media with no real modification or loss, but this is not a real issue along the Perth/Swan Coastal Plain as P is the limiting nutrient in the receiving waters. And this is one of the things that UNDO can assess, Jim said it was a very good model
27	Regarding water quality, Jim said that projects don't get held up because of this, it is water quantity that is nearly always the issue. Hence the answer to Q 27 is a firm no.
Surface Water Flows	
28-30	Post development, peak surface water flows are generally going to increase, time of concentrations will decrease, runoff volumes will increase (noting that if there are sandy soils projects may infiltrate much of the total runoff). In a lot of JDA projects, they present data supporting the use of low runoff coefficients from urban development. There is little peer reviewed research of these processes that can be drawn upon - which can create issues with the Department of Water approving such. Jim feels that there is a need for more peer reviewed work for this to be reliable. Hence reference to support for preparation of a WA Urban Drainage Manual that may include some peer reviewed and accepted findings. Carolyn Oldham's work was discussed, Jim agreed that Carolyn is more quality than quantity based. His view is the reverse…..Jim's view is that placing contemporary urban developments on top of (*appropriate*) imported fill is actually improving water quality. Contemporary urban designs have such small lots and small gardens that nutrients are far less of an issue than people think/or are used to. Often only 10% of such sites are irrigated and fertilised and hence a source of potentially 'fertilised' groundwater recharge.
30	They use XP modelling with appropriate runoff coefficients. Have just completed a flood study for the WA Water Corporation simulating the Swan Coastal Plain in a pre-developed condition. Jim noted that AR&R does not provide any guidance regarding this issue for the coastal plain, only for the hills areas, hence the need for their work. Post development, it's all about

	initial and continuing loss. There is a low level of interest in flood matters in WA as there is very little flood damage
Surface Water Quality	
31-32	Jim felt that we had covered these issues adequately earlier in the interview process.
Harvesting and Managed Aquifer recharges	
33-35	JDA are doing a few MAR projects, it's not just storing but also about reusing. They are involved in the Nambeelup project and also have done work for the City of Swan on MAR options. MAR is 'flavour of the year' as WA is short of groundwater, targeting supply to urban development and importantly POS. MAR provides additional supply to often fully allocated aquifers. More soakwells can help….may also then enable a higher extraction rate. Jim said MAR schemes in the superficial aquifer will only work where 'you have a bit more clearance' to the groundwater table. Infers that MAR may only work in areas where there are not high groundwater tables, unless there are uses for the water all year round (e.g. Nambeelup and horticultural supply)..
35	There are a few administrative and knowledge base hurdles to the practical widespread application of MAR, National and Local Guidelines need to be worked through, increasingly proponents are looking to MAR projects
Development	
36-37	Note earlier comments on high density vs low density developments, widespread use of subsoil drains.
General	
38-39	Lack of a suitable and appropriate design standard, especially for infiltration rates (initial and continuing losses). Key contested issues are infiltration rates (initial and continuing losses).
40	Tim Sparkes (DoW), Steve Watson (DoW), Don McFarlane (ex CSIRO - recently retired).

Interview response six (Clay Thomas)

Name	Clay Thomas
Organisation	Peet Limited
Interviewer	Andrew Telfer

Question	*Response*
General	

1	Developer, essentially the client. Answers may not be technical, but from context of developer.
Water Balance	
2	From developers perspective, water balance gets considered early in the process. Need to understand water balance driven by consideration of approvals and cost implications (eg water treatment, soak wells, rainwater tanks, cost of park development, stormwater drainage (surface runoff, subsoil drainage). These costs are considered before purchase, and consultants are brought on board before purchase. The other big issue is fill costs – where do groundwater levels sit and how much clean fill do we need. This drives innovation. Need for fill is increasing, supply is not constrained and price is not increasing significantly. A lot of new urban land is with high groundwater tables.
Water Quality	
3-9	• Clay's water quality perspective more to do with obtaining approvals. Once land acquired, need to prove to authorities that the development is going to maintain water quality. Landscape Master Planning and Local Water Management Strategy (LWMS) paint the picture for the authorities. Getting LWMS approved is key KPI for hydrologists. • Clay has only recently started working over shallow water tables so no direct experience with performance of WSUD elements over shallow water tables. New project starting now will involve significant monitoring of shallow water tables. • From a development managers perspective, who rely on experts, there is an appetite for innovation either through biological or technological techniques. Nationally there are some quite complex biotreatment systems, but the systems do not seem to be implemented in Perth to any significant extent. For example, biofiltration has not, from what I have been involved in, been developed significantly in Perth
Flood Risk	
10-13	• Flood risk is always an issue. Biggest issue is capacity of stormwater drainage system from both cost and amenity perspectives. Flood control basins are deep and dry most of the time, which is a poor outcome from an amenity point of view for a basin that deals with a 1:100 flood event. Would like to see innovation in relation to designing flood mitigation in order to improve amenity. The stormwater management strategy affects amenity which affects the list price which in turn affects the ability to enhance the amenity. In Perth, more cooperation between private and public sectors could see use made of Bush Forever sites (for example) to be used for managing flood risks and infrastructure amenity. • Stormwater on roads – centre of road to outer edge only 50mm compared to say 200mm in Adelaide. Kerb mountable or semimountable, at approximately same level as road pavement. Moderate to heavy events will overtop the kerb and go overland. Gutters not generally designed to

	convey water to a treatment location, rather to spread over the near-road verge.
Groundwater Level	
14	• Methods – imported fill and usually subsurface drains, open drains are less common now. • Soak wells not as common as they used to be, and houses getting bigger, so soak wells not as common. House drainage drains into subsoil drains which connects to under-road subsoil drains running to lowest point in the development or adjacent wetland or to the ocean. • A recent development for a few projects in perth is the implementation of a swale for water treatment in the space between the road and the footpath.
21	The current approach is based on one or more cross-sections of pre-development groundwater levels. The next stage can and perhaps should be a three-dimensional view of groundwater levels. The issue with the 2D approach is that assumptions are sometimes not bourne out in reality, and after first stage developer has found that much more water disposal is required which impacts on overall profitability. Most developers would prefer to spend more budget on getting good quality quantification in the first instance, because it costs much more to retrofit a design.
Groundwater Levels risk	
22-23	Groundwater levels do rise, but not problematically. RPS (Karl Davies PhD) is looking at post-development groundwater levels north of Perth. As a developer, not aware of any obligation to monitor post-development groundwater levels, although post-development groundwater quality monitoring is required
Groundwater Levels Benefits	
24	Need to consider high groundwater levels as an asset. High groundwater table with open creeklines and high amenity value, adds value to the project. Design site to maximise benefit. This requires innovation.
Groundwater Quality	
25-27	• Aware of bioretention basins, which could be used much more. Currently sandy swales with reeds. • Port Coogee – manmade marina on the coastal side of industrial and market garden areas. Groundwater nutrient rich, with risks for algal blooms. Groundwater interception drain was connected to a pump station and treatment facility and returned through third pipe non-potable water.
Surface Water Flows	
28-30	No response
Surface Water Quality	

31-32	No response
Harvesting and Managed Aquifer recharges	
33-35	Looking to use it in the next development. Struggling with benefit/cost. Initial design is shallow pumping to deeper injection, but not clear that it is cost-effective
Development	
36-37	• Peet now have a presence in SA, and acquired CIC Australia which built Lightsview, which is in cracking clays with lightweight timber framed construction, and this capability is being imported to WA where the capability is very low in this building style. Perth is only state where it is cheaper to build brick rather than timber, because engineered timber has to be imported, and carpenters are expensive. • Traditionally, with sandy soils and abundant sand fill, all sites are Class A (WA). That is, no soil reactivity. Which means slabs are cheaper. But now moving into S and M classes, which need more robust footings and therefore they cost more to build but cannot be sold as A class. But if fill brought in, can charge more for A class.
General	
38	Innovation is encouraged, but the cost and implications of management mean government and councils often resist taking on new management requirements without experience or expertise. The science and engineering stack up, but no appetite by Government for volunteering funds or managing a facility. Advocacy is required to encourage innovation. Getting approval for innovation – this requires advocacy and co-funding.
39	N/A
40	None noted

Interview response seven (William Glamore)

Name	William Glamore
Organisation	UNSW
Date	22/1/2018
Interviewer	Andrew Telfer

Question	*Response*
General	

1	Reviewer and Science relating to surface groundwater interactions.
Water Balance	
2	Uni working on climate change impacts on shallow groundwater tables (PhD) and other projects across estuary scale down to paddock scale. Designs try to engineer around shallow water tables eg Perth in sandy soils, the Ord River Scheme – different soils, also estuarine clays in NSW/Qld. In NSW, most of shallow groundwater is peri-coastal/floodplain in the eastern flowing rivers. Some issues on the River Murray. At Newcastle, in peri-coastal environment, RAMSAR wetland located adjacent new industrial development. Need to consider how to maintain both wetter and dryer sequences. Soak wells can increase infiltration, and increase watertable elevations, with detrimental impacts to adjacent wetlands. The "solution" was to bring in 2m of fill, which didn't address the need to maintain drying opportunities for the wetlands. A typical outcome, which can have a broader detrimental impact, especially for smaller sites. In other locations, an alternate approach was to set up infiltration basins until groundwater level triggers were reached, at which time the additional water was pumped to the next catchment – this was less than optimal as it affected the next catchment adversely. Looked at links with hydrology and ecology outcomes – Central Coast NSW. General approach is improving, from regulators to developers – considering the entire water balance – but everyone is trying to do it as cheaply as possible. To do it right, needs a maintenance program and that is a significant hindrance. A Perth site applied a levy to landowners, and similarly on the South Coast NSW. There is a big push in Sydney and Hunter Basins to develop these types of sites (estuarine fringe). Typically flooding is also a concern and evacuation is a priority – these tend to be the construction drivers, can you build a house on a pad, or on a frame, to manage the flooding risk. Shallow groundwater also typically associated with Acid Sulphate Soils. NSW and Perth are similarly challenged in finding solutions. State govt appear reluctant to set a standard for these types of development – mostly comparative assessments are used in estuarine settings, which can cause a problem where the best outcome is still a poor outcome. Stormwater drainage, retention ponds are different to rainwater tanks (BASIX scheme – x% of water storage compared to baseline, and some "biotreatment"). Biofilters (swales) in shallow groundwater systems often get clogged by chemical iron precipitation, - they no longer work as they should do. Iron is higher in NSW, because heavy clay with pyrite in the Holocene/Quaternary clays. Soluble iron concentrations can exceed >100mg/L. Theoretical design and hydraulics is mostly OK. But in models (eg MUSIC) there is limited local testing to determine if the parameterisation is appropriate. So the model based design inputs may not represent the site parameters.

	High reliance on MUSIC as a tool, which leads to industry belief that the model is a good representation of reality, which may not necessarily be the case. William tends to use hydrodynamic based models, and a range of tools and seeks to inform them with local data (including PHREEQC). William suggests regulators need to specify a standardised empirical data collection framework to validate model outputs and make sure that the models aren't missing something important.
Water Quality	
3	N/A
4	N/A
5	N/A
6	Not overly familiar with the Adoption Guidelines for Stormwater Biofiltration Systems, Payne et al. 2015 as he hasn't regularly seen it noted. Constructed Wetlands Manual is referred to frequently, but has been around forever. ARQ Guidelines also well referenced. New Queensland Wetland Technical Design Guidelines in May 2017 seems good (by Water by Design). They may have done a stormwater one as well. Generally better, because it provides equation and its derivation, and the input requirements. Whereas MUSIC is a black box, and is too often used without checking if the inputs are appropriate or the outputs realistic.
7	N/A.
8	Spearpoint Sands in the Peel Harvey Estuary have been proclaimed a good material for use in swales/drains because of superior nutrient uptake. Higher rates of uptake appear to occur because of slightly higher organic levels, but the benefits appear to be oversold. Organics can take up some nutrients, but only modest improvements. In the Ord, significant funds spent on spearpoints and drains over 10,000 ha to manage agricultural drainage inputs.
9	N/A
Flood Risk	
10	Don't see enough measuring flows and events – rainfall, runoff, water quality, groundwater response. Hydrology 101 is still really important for design. Antecedent soil moisture conditions not often considered in designs. Design scale assessments often use different consultants for groundwater and surface water, and very often the loss rates/recharge rates do not agree – need better integration of surface/groundwater disciplines.
11	N/A.
12	Infiltration rates are often used as a "calibration" parameter.

13	Only worked on that in the water quality space. Grantley Smith would know more about if from the flood side. But very few people consider groundwater in designing infrastructure unless there is contamination..
Groundwater Level	
14	Very rare to see an urban development in a greenfields site – tends to be incremental changes. At one site in the Hunter, the wetland at base of catchment now permanently wet potentially due to increased runoff and higher groundwater levels.
15	N/A
16	Spearpoint pumping at Ord River. Also intercatchment transfers.
17	Geoprobe. Hand augers. “Dingo” with modified head for push tubes in <1m to groundwater.
18	N/A.
19	See discussion above. Prefer using analytical methods, particularly at the first stages, to gain confidence in the outputs.
20	N/A
21	Very little done to look at post-development groundwater levels, and very few policies in NSW to support collection of post hoc data. In Qld, there has been good legislation looking and pre- and post- development groundwater levels with indicators and benchmarks within policy (eg SEEP Guidelines)
Groundwater Levels risk	
22	Yes. Expect groundwater to rise under development. And in coastal areas groundwater usually salty, with impacts on infrastructure and water quality.
23	Have seen this becoming more commonplace with new ARR
Groundwater Levels Benefits	
24	There can be significant ecological benefits from shallow groundwater systems. If the land is generally wetter, then less frequent blackwater issues.
Groundwater Quality	
25	With PFAS c- pump and treat, also permeable reactive barrier systems. Hemp can be used to bind PFAS onto the roots – swamp melaleuca can bind iron and metals
26	Advocate measuring flux as well as concentration. ARQ talks about it a little, but not often done.
27	N/A
Surface Water Flows	

28	Many useful books.
29	Retention basins or retention wetland (eg1000ha) in the catchments because it solves water quality and also flood retention, which may be better than lots of little basins.
30	Need enough resolution to pick up important drainage and stormwater infrastructure – can be poorly done if resolution not considered.
Surface Water Quality	
31	Encourage use of wetlands – treatment trains – trying to integrate the coastal tidal exchange
32	Design based on fieldwork and onsite measurements, numerical modelling, more design, then post construction monitoring and review.
Harvesting and Managed Aquifer recharges	
33	In shallow groundwater systems it was in vogue a decade ago, but not seemingly so recently in coastal NSW. A system near Newcastle has problems with generating localised flooding. Council capture and recharge on small scale. Deep/shallow system geochemistries are so different, need to consider contamination risks from shallow systems
34	N/A
35	N/A
Development	
36	Fill is mostly used. Emergency response and climate change (Lake Macquarie Council has an approach in some areas that they will raise the infrastructure to manage effects of climate change).
37	N/A
General	
38	Key impediment is good, evidence-based policy that guides developers in what needs to be done (eg best practice). Policies are available for basics (eg energy, water use) already, but not enough guidance in the shallow groundwater space. Also, better empirical information on data and processes. Unsaturated zones are not at all well known..
39	Outcomes from hydrology indicators are better understood, water quality indicators are moderately well understood, but the implications of ecology indicators are poorly understood.…. Also, too much reliance on MUSIC.
40	Proponents may feel otherwise – a number of them may be worth talking to. Prof Anna Deletic was a key contributor to MUSIC and may have a different perspective on its value. eWater may also believe that a lot of the modelling work is well done – especially the hydrology/runoff chemistry. ADW Johnson (engineering consultant) do a lot of work in this space in residential

	developments and may be worthwhile consulting for a NSW perspective. Not many urban groundwater researchers in Sydney (who work on basic hydrology and hydrogeology

Interview response eight (Peter Dillion)

Name	Peter Dillion
Organisation	WGA, honorary roles CSIRO and NCGRT
Date	5 Feb 18
Interviewer	Andrew Telfer

Question	*Response*
	General
1	WGA, honorary roles CSIRO and NCGRT
	Water Balance
2	High water table areas need more focus on ET and runoff due to limitations on recharge. Yes, has significant impact on site water balances. Olga Barron did a lovely study WA Premiers Research Foundation, all encompassing, on the Southern River Catchment, with sophisticated modelling to support fate of water and nutrients. https://www.water.wa.gov.au/__data/assets/pdf_file/0019/5077/95903.pdf https://www.researchgate.net/publication/267947781_Application_of_a_coupled_surface_water-groundwater_model_to_evaluate_environmental_conditions_in_the_Southern_River_catchment Olga.Barron@csiro.au Groundwater studies have been done but groundwater impacts are understudied in the urban domain. Not a single WSUD study in Adelaide mentions depth to groundwater – ie recharge constraints to groundwater not considered, yet Western Adelaide Plains has shallow depth to water, and is infact drained by leaky sewers. Deeper systems may be available for injected/drained recharge or draining shallow water table to deeper aquifers and then using shallow aquifer for recharge.
	Water Quality
3	Best answers by Shiroma Maheepala – lovely study of sources of nutrients to Brisbane coastal waters, showing the dominant inputs are from rural sources and urban inputs are comparatively low.

	In Adelaide, concentrations in stormwater are lower than in natural systems. Metals and surface water clarity may be more important parameters for stormwater. Need clear view on what the loads are from stormwater, then protect the ecosystems against key parameters, rather than assume nutrients are the key parameters of concern.
6	Biofilters often have clay liners or concrete bases and are not interacting with groundwater. Biofilters, if recharging groundwater, should take account of the National Managed Aquifer Recharge guidelines for chemistry and microbiology, including threshold values
7-8	Not seen these being done.
9	Water quality requirements for receiving water, where these are aquifers, are rarely considered
Flood Risk	
10-13	Significant opportunity to mitigate flooding by increasing detention storage to sustain catchment vegetation. Perhaps focus is on small storms, but could be increased if larger detention storage could be implemented throughout catchments eg Treenet. Regulatory framework not supportive of increasing detention at household scale. Opportunity to develop a development-based water entitlement scheme at household scale to cover offset costs for council pay for distributed flood management. Initial calculations suggest it would be viable (ref).
Groundwater Level	
14-21	• Stephen Foster did a lot of work in this area. Not sure what has been done in Australia. Peter has done a study that suggested that 10% of metro Adelaide groundwater levels were controlled by the sewers. SAWater installed a saline wastewater treatment system to cope with the wastewater from these areas. • It could be an interesting study to see response of groundwater to changes in pervious area and garden irrigation. Don McFarlane and Blair Nancarrow worked on this in the 80s. (ref UNESCO document). Water levels may fall as garden sizes decrease. (less irrigation) • Peter Laut and Neil McKenzie – Australian soils data across Australia. CSIRO has been using infra-red techniques for characterising soils, which once trained on a soil type can be implemented readily. • Huge opportunity for mobile phone based groundwater level monitoring, such as is being applied in the MARVI project in India that Peter is involved with. Can get more quantitative data using this method. • In considering recharge and WSUD, the issue of groundwater protection may be more significant than the impications for surface water and infrastructure management. However, if there are infrastructure problems, the costs could be high.
Groundwater Levels risk	

22-23	Yes, would expect interactions between gw and sw.
Groundwater Levels Benefits	
24	• Olga Barron's work on GDEs. Builders lifting houses and roads by a metre. Her work showed that raising ground level was an effective solution. However, if you build out and remove ecosystem functions then you will need to reinstate the function at some cost. Developers have no ongoing responsibility for ongoing costs. • Do need to develop and implement natural engineered approaches in shallow water table areas. Design considerations include clustering buildings on "pods" and retaining wetland functions.
Groundwater Quality	
25-27	• Iron is an issue in Perth. If groundwater used for drinking water, need to consider pathogens, pesticides, metals. Need to consider groundwater as a receiving environment. Chris Barber, Greg Davis and Munna Sharma studied the Gnangara mound and the water quality and the sources of contamination. Evidence from that work related land uses to contaminants in groundwater. • ANZECC guidelines 2000, and Commonwealth Groundwater Protection Guidelines were updated in 2013. Dept of Environment released them without much fanfare, but very relavent for urban development. The environmental values of aquifers need to be specified.. http://www.agriculture.gov.au/SiteCollectionDocuments/water/nwqms-groundwater-quality-protection-guidelines.pdf
Surface Water Flows	
28-30	No Comments
Surface Water Quality	
31-32	No Comments
Harvesting and Managed Aquifer recharges	
33	A range of options available. Recharge capacity is not only dependent on the shallow aquifer – deeper aquifers need to be considered in assessing potential.
34	In Darwin, considering recharge into fill and spill aquifers as a precaution against drought. These need good hydrogeological studies to inform decision making, and dedicated investigation well construction to provide empirical data for decision making. Regional extrapolation is not enough. Geophysics, aquifer testing, water quality are all important.
35	Can be a solution for managing high groundwater, but need to understand demands and supply opportunities. Need priorities – is it for maintaining a particular groundwater level, or for a water supply.
Development	

36	Shutter foundations in Adelaide in expansive soils are being usefully applied
37	N/A
General	
38	Information on hydrogeology would be the key impediment faced by developers and consultants.
39	Do we know what the ecosystem requirements are? And what constraints need to be placed on groundwater levels and quality to maintain ecosystem or water supply services.
40	• Olga Barron, Don McFarlane (retired, consulting in Perth (Don McFarlane <don.mcfarlane@outlook.com>)) • MARSUO (MAR and Stormwater Use Options) Summary report on Goyder Website, with eight other reports (economics, risk assessment, risk management, stormwater impacts, runoff times, harvesting of stormwater for drinking water etc). here are two: http://www.goyderinstitute.org/_r106/media/system/attrib/file/97/MARSUO-Summary%20of%20Research%20Findings-final_web.pdf http://www.goyderinstitute.org/_r105/media/system/attrib/file/96/U.2.1.%20MARSUO%20Net%20Benefits%20Report%20%28T5%29_for%20RAC.pdf • John Radcliffe produced a paper on 50 years WSUD in Salisbury. It started out as high water table flood prone land. John.radcliffe@csiro.au

Interview response nine (David Close)

Name	David Close
Date	9/2/2018
Time	3:30- 4:00 AEST
Interviewer	Tony McAlister

Question	*Response*
General	
1	Reviewer and Approver. David works a lot with and around the QLD State Planning Policy (SPP) instruments, especially if there are gaps in their own Planning Scheme. He commented up front that Moreton Bay Regional Council (MBRC) does not have a lot of groundwater issues, but that they did pop up from time to time

Water Balance	
2	David discussed that Bribie Island (a large sand island to the north of Brisbane) is the only real area in MBRC with any potential issues. Development in areas that are or may be potentially affected by high groundwater levels (which are mostly low lying) is usually not allowed to proceed for other reasons (e.g. flood inundation risk, sea level rise potential, etc noting that these are all defined under predicted 2100 sea level rise/tailwater conditions) than high groundwater tables. If development does occur, there is a requirement for sufficient fill for flood reasons (though filling in flood (as opposed to tide) prone areas is not generally allowed due to the associated loss of floodplain storage) such that this would avoid any groundwater issues, but their preferred approach now (included in their Planning Scheme) is actually avoidance. The mgmt. action is AVOID. No significant groundwater modelling is really being undertaken, unless there are areas of ASS or PASS where Council may be concerned about water quality impacts
Water Quality	
3-9	• Nutrients go up, Council has lots of data, they have a Total Water Cycle Management Plan (TWCMP) that sets catchment specific goals. Every development over 6 lots need a water quality assessment using MUSIC and this sees the incorporation of appropriate stormwater quality improvement devices (SQIDs). This is resulting in lots of piecemeal devices. They cannot regionalise these devices unfortunately under their LGIP. • In regard to WSUD devices in areas of high groundwater, David knows of some problems associated with the Kipparing Rail Project, primarily though due to tidal driven groundwater inundation and with associated flows actually surcharging up into the WSUD devices causing sudden dieback of plants! • Everything they do WSUD wise is in accordance with the Healthy Land and Water (HLW) Water by Design (WBD) guidelines and the Queensland Urban Drainage Manual (QUDM). • They require no consideration of near surface groundwater levels in the design of WSUD infrastructure. • Locally sourced materials – MBRC requires the testing of all biofilter media to ensure that it complies with modelled/required nutrient levels and permeability specifications – this causes complaints as there are only one or two sources who have the market cornered - this is a potential instance of monopoly pricing! • Methodologies and lack of data are not an impediment to projects. WBD and QUDM are more than sufficient. Discussed some LGA's having locally specific parameters that supersede these guidelines .
Flood Risk	

10-13	David has very little to do with flood issues. MBRC does have a standard Regional Floodplain Database (RFD) approach to flood management that is applied across the whole LGA and that does not specifically relate to issues of high groundwater. This is Allan Charteris' area of specialisation. David has two team members who deal with simple flood checks/issues, anything greater than this is referred to Allan's team.
Groundwater Level	
14-21	• Changes in groundwater levels post development don't really occur to a degree that there are any noticeable effects in MBRC. • Any actions at all are related to fill. • Soil details/groundwater levels etc if they are required are defined from first principles (e.g. boreholes, drilling, etc). • How many infiltration sources are considered post development to assess groundwater levels – none. • Pre and post development groundwater levels are rarely considered. • Their existing approaches are all quite simple and robust and sufficient for their purposes.
Groundwater Levels risk	
22-23	They don't have any real issues. No interactions with stormwater infrastructure occur to the best of his knowledge, this is more sewer related due to the depths of sewers in some areas of the Council. They have not had to/don't consider groundwater impacts in terms of changing the conveyance capacity of stormwater infrastructure under differing ARI/AEP events.
Groundwater Levels Benefits	
24	Natural approaches can have benefits in regard to public amenity and the environment. Mosquito control was mentioned as an issue though where there is too much vegetation and potential standing water, needs very careful consideration or can create a real nuisance
Groundwater Quality	
25-27	• No measures are used by Council to treat near surface groundwater. • No measures are used by Council to calculate pre and post development groundwater quality. • No data impediments exist.
Surface Water Flows	
28-30	Surface water flows go up, detention basins or receiving water have to be capable of handling the elevated flows, legal point of discharge (LPD) issues were discussed.

	Standard hydrologic and hydraulic modelling and detention techniques are applied across MBRC to manage and understand surface water flow related issues
Surface Water Quality	
31-32	• Biobasins, wetlands, proprietary devices (a few) are used across most projects in MBRC. Cartridge type proprietary devices are only approved on community title type developments where Council can be assured that they will be maintained appropriately. MBRC are doing very little monitoring of any SQID's. • MUSIC and WBD guidelines are widely used and accepted as standards.
Harvesting and Managed Aquifer recharges	
33-35	There are no applicable projects in MBRC.
Development	
36-37	There are no applicable projects in MBRC.
General	
38-40	No real comment on this, MBRC has not to David's knowledge had any projects that have not proceeded due to high groundwater issues. Don't have any contested areas as they try to avoid areas where this may be of concern.
40	Allan Charteris would be good to talk to

Interview response ten (Peter Newland)

Name	Peter Newland
Organisation	Newland Water
Interviewer	Andrew Telfer

Question	*Response*
General	
1	Mostly as a regulator, some more recently as a practitioner
Water Balance	
2	All aspects impact on site water balance. As a regulator, importance was on the impacts of water leaving the site – ie worried about the receiving waters

	more than the performance of WSUD. Not a lot of information on shallow urban water. See Baden Powell report.
Water Quality	
3	Generally increased levels of nutrient and impact on local streams. Plenty of reports in EPA, but not to hand. Extra impervious surface has reduced recharge to groundwater. Tonkin report on an increase in the impervious services in Marion & Holdfast Bay will increase runoff by 20%. Check this number in Cities of Marion and Holdfast Bay Stormwater Management Plan https://www.marion.sa.gov.au/page.aspx?u=866 http://www.holdfast.sa.gov.au/page.aspx?u=4904&c=17367
4	Is there benefit in rainwater tanks? Probably yes, from reducing flooding, increased water use in the suburbs, not much water quality improvement.
5	No experience in high groundwater environments although I have worked in areas of Adelaide (e.g. Mawson Lakes) where cut and fill has been used elevate base levels above groundwater. Also in coastal areas where freshwater stormwater wetlands have been lined to prevent saline groundwater ingress.
6	Bill Till wrote a fantastic set of WSUD guidelines for Perth, but they do not seem to have been carried forward or adopted.
7	No direct experience.
8	Andrew King at West Torrens Council did quite a bit of work looking at local aggregates. Robin Allison (DesignFlow) also.
9	WSUD is not a legislated requirement, and should be. Another paper by Peter and Baden Meyers on this subject. Baden and David Pezziniti (Uni SA) have done a number of papers through the Goyder Institute re WSUD. Michele Akeroyd was past CEO and may be another useful contact.
Flood Risk	
10-13	No significant practitioner experience
Groundwater Level	
14	Increase of impervious surfaces can lead to reduction in recharge (eg Adelaide), but increased irrigation can cause increases in water levels (eg Las Vegas) and also reduced use of urban groundwater can lead to increases (eg London). Someone at Adelaide Uni has been looking at Quaternary water levels.
15	No, but would be interested to know.
16	Andrew King at West Torrens Council has mandated something like 300mm of fill before development to mitigate flood risk, but there will be shallow tables in Lockleys/Fulham adjacent the Torrens.
17-21	No significant experience.

Groundwater Levels risk	
22	There is a risk, particularly in saline environments, and a need/desire to keep good quality stormwater separate from saline groundwater intrusion.
23	Did look at that in the Lower Murray Swamps. Haven't looked at it from a design perspective
Groundwater Levels Benefits	
24	Avoiding pumps and pipes is a good outcome. Floating houses have been built in the Netherlands and on the Thames. Simpler to avoid areas where these issues occur.
Groundwater Quality	
25	Mostly considered stormwater, not the groundwater
26-27	No significant experience
Surface Water Flows	
28	See 14 above. Probably reduced recharge, but in parts of Adelaide where basements are wet, there is a new baseflow from pumping the basements.
29	No significant experience – promoted WSUD at the regulator level to improve water quality.
30	No significant experience
Surface Water Quality	
31	Involved with a lot of the catchment management improvements, extension officers in Councils (but no longer). The extension officers did provide a useful service, but need a carrot and stick approach but Government never really got the stick out. Which was a missed opportunity. Driving attitudinal change needs to be an ongoing process – can't do it for a while then drop it without the benefits deteriorating
32	No significant experience
Harvesting and Managed Aquifer recharges	
33	Considered and highly supportive of it. Currently a practitioner with the City of Playford, but not in shallow groundwater environments. Need to manage the water quality implications for the receiving groundwater.
34-35	No experience in high groundwater
Development	
36	Floating houses. Avoidance. Not keen on fill.
37	No relevant experience

General	
38	As a regulator, Peter was trying to facilitate WSUD implementation. It is true that operations and maintenance issues can constrain implementation. Large projects can be more cost-effective that small projects.
39	Why do it in the first place? Is it better to avoid these locations?
40	Baden Meyers at Uni SA. Recent paper on Adelaide Urban Groundwater and where there are any issues.
Comments	
• I contacted Baden Myers and he would be happy to discuss what he has done in Adelaide on shallow groundwater tables and Goyder WSUD documents. Contact email is:Baden.Myers@unisa.edu.au • I sent an email to Bill Till in WA but have not hade a response yet – he is retired now and I have not been in contact for 18 months.The documents he helped produce are on the WA water website and some appear to be updated. Link is:http://www.water.wa.gov.au/urban-water/urban-development. I am not sure who has carriage of them now. • The City of Marion & Holdfast Bay Stormwater Management Plan could take some digging to see the full document if you want to.	

Interview response eleven (CJO 5)

Name	CJO 5

Question	*Response*
General	
1	Practitioner and reviewer.
Water Balance	
2	They all play an important role to the overall site water balance. With focus on groundwater level (my main area of expertise), I have seen evidence of: a) Local groundwater level mounding due to soak well systems that resulted in water ingress into a basement and/or attributing to damp in buildings. b) Establishment of new sub-divisions have resulted in rising groundwater level, which is considered to be related to change in vegetation and stormwater drainage (use of basins and soak wells).

	Yes I have assessed such impacts. I did not use any particular method, but analysed hydrographs and incorporated this into numerical 3D groundwater models to model impacts.
Water Quality	
3	I have the following experiences: a) I have in multiple areas seen the effect on ASS from developments, mainly in the Perth CBD area, where low pH and high metal concentrations have been observed in groundwater following construction dewatering and/or installation of retaining walls (the retaining walls can act as groundwater flow barriers, resulting in permanent change in groundwater level that can cause exposure of ASS). b) Development of subdivisions, which introduces reticulation systems, can effect groundwater quality. I have had one experience where I found through water sampling that the scheme water used for reticulation of lawns had higher nutrient concentrations that the groundwater in the area. The results indicated that the use of scheme water for reticulation could have resulted in an increase in nutrient concentrations in the groundwater aquifer
4	All the listed components will to some extent have an effect on groundwater quality. I would expect (not directly evidence based): a) The change in stormwater drainage (impervious surfaces, retention basins, soak wells, etc.) will generally have the greatest effect. b) In WA there are now quite strict guidelines on fill placement, which is likely to have decreased the impact fill now has. However, there are in Perth significant historical examples where placement of ASS fill resulted in significant groundwater contamination. PFAS is now becoming an emerging contaminant of concern and there are particular concerns that this can be transferred in fill and affect groundwater at new sites.
Flood Risk	
10-13	N/A
Groundwater Level	
14	Urban development can result in both decrease and increase in groundwater levels. The assessments I have undertaken have mainly focused on where groundwater level rises may have occurred or are occurring as a result of urban developments: a) Some groundwater level data in part of northeastern suburbs indicates rising groundwater level trends, which could possibly be related to urban development. b)Groundwater levels in some southern suburbs seems to have rising groundwater level trends that could possibly be a result of urban development and particularly stormwater drainage and subdivisions. Examples of decrease in groundwater levels can be found throughout Perth metropolitan area where surface drains are installed to control groundwater

	levels and allow for development. Publicly available hydrographs shows step changes in groundwater levels following the installation of these drain systems.
15	No particular method has been used. The analysis is undertaken mainly through review of historical groundwater level data (hydrographs) and in some cases by establishing groundwater models to assess changes in groundwater levels due to change in recharge, groundwater abstraction, installation of basins/soak well systems and installation of drains
16	I have been part of projects that have used many of the different listed measures: a) The use of fill to increase clearance is not uncommon practices throughout Perth. The potential issue can be that the pre-development shallow groundwater level are controlled by existing drainage, vegetation and evapotranspiration. The import of fill could change this dynamic and groundwater has been found to rise up into the placed fill to establish a higher groundwater level equilibrium. b)The use of sub-soil drainage are also quite common in Perth, maybe less now than historically due to the possible impacts that it can have on groundwater quality at the site and issues obtaining approval for disposal of water from the sub-soil drainage system (this reference is mainly made to drained basements in the Perth CBD).
17	I consider the following information useful: a) The 1997 Groundwater Atlas prepared by the now Department of Water and Environmental Regulation (DWER), which presents inferred historical maximum groundwater level in part of the Perth Metropolitan Network. b) The Water Information Reporting database operated by DWER. This data has valuable information on well information, soil profile and groundwater level, though the data quality is sometimes poor and needs to be scrutinized carefully. c) The 1:50,000 Environmental Geological Map series provides good information of surface geology and normally also includes bore logs soil profiles on the back page. d) The Perth Regional Aquifer Modeling Systems (PRAMS) report series prepared by DWER provide good background information on the Perth geology and aquifer systems.
18	N/A
19	There are several different possible methods to calculate pre- and post-development groundwater levels. I consider a useful method to be the Cumulative Departure From Mean (CDFM) method when limited groundwater level data is available (which is too often the case). The CDFM method can be quite helpful when estimating historical groundwater levels and Design Groundwater Levels and distinguishing between climate and other effects. Otherwise I consider groundwater modelling to be the strongest tool to assess

	pre- and post-development groundwater levels (note that this can be basic groundwater models). I do not agree with the Average Annual Maximum Groundwater Level (AAMGL) method that still seems to be used by some practitioners and local councils in assessing Design Groundwater Levels.
20	N/A
21	I believe that this is an area where further development is required to establish proper pre- and post-development groundwater levels and Design Groundwater Levels. I also think that it is important that the government office recognizes and invests in proper groundwater level networks to assist with the assessments (the regulatory 18 months groundwater level monitoring requirement is insufficient as standalone information and will need to be considered together with long-term groundwater level data). The groundwater level monitoring network in Perth Metropolitan area have significantly decreased since the 1980s, both in number of locations and monitoring frequency. In the 1980s groundwater levels were monitored monthly in DWER monitoring network, which was then in 1990s changed to quarterly and is now biannually (with the aim of measuring the dry and wet season groundwater levels). However, there seems to be a slight shift in the seasonal groundwater level fluctuations, which could become even more evident with the changing climate, which is not being properly picked up with the current monitoring network and frequency (it is very unlikely that the measured groundwater level reflects seasonal maximum, though the data is being used as such). Given, how much technology has developed over the last decades with groundwater level loggers and telemetry, it would only seem sensible that the groundwater monitoring network should reflect this and with a relatively small investment the groundwater network could be significantly improved.
Groundwater Levels risk	
22	Absolutely. I believe that the depth to groundwater level is the main factor for the lack of success for many of such underground stormwater drainage structures.
23	I have not personally have to do this. But I do find in our industry that one consultant may be dealing with the groundwater issues (e.g. as part of the geotechnical scope) while another consultant deals with hydrology and stormwater system design. In many cases there are limited interaction (other than potentially providing infiltration rates for stormwater basin design). I consider this approach to be flawed as the stormwater design will effect Design Groundwater Levels and cannot be designed in isolation of groundwater.
Groundwater Levels Benefits	

24	No not necessarily. I generally believe (within reason) that the first approach should always be to minimize potential environmental impacts on any project. But I also think we have to accept that development will result in change and thereby impacts, particular in Metropolitan areas where it has been decided that significant development will occur.
Groundwater Quality	
25-27	N/A
Surface Water Flows	
28-30	N/A
Surface Water Quality	
31-32	N/A
Harvesting and Managed Aquifer recharges	
33-35	N/A
Development	
36	I can think of the following alternatives that are more commonly used now: a) Tanked (water proofed) basements rather than drained basement seems to become more common. I believe that some of the key reasons for this are regulatory but also reliance on sub-soil drain systems that can/will fail over time without continuous maintenance. b) Redesign of buildings where "basement" are moved above groundwater table due to regulatory restrictions on discharge of groundwater (both during and after construction). This could reduce number of car parks for the development or result in the over ground car park levels.
37	I can think of the following: a)I believe there are several examples in the Perth metropolitan area where the use of sub-soil drains beneath basements have failed over time because sub-soil drains are clogging up due to high iron concentrations in the groundwater, which precipitates in the drains. b) I believe there are several examples in Perth where the installation of a grout plug beneath an excavation inside retaining walls (the intention is to reduce construction dewatering) have failed.
General	
38	During the construction phase (which I mainly deal with) the two most common reasons are: a) Disposal of abstracted water during construction dewatering b)Potential impacts on ASS due to groundwater level drawdown

	Otherwise stormwater drainage seems to be one of the key impediments facing developers.
39	The interaction between groundwater and surface water practitioners during stormwater designs is in my experience areas where the greatest disagreement can occur. In my experience many of the used stormwater basin design packages do not consider the effect that the presence of near-surface groundwater has on infiltration capacities from the basins.
40	I think it is very important that the regulators view are also included in this discussion. A person that I think it could be interesting to talk to is Jennifer Stritzke from DWER (formerly at Swan River Authority). I think that she would be able to contribute to the discussion on some of the topics from a different angle than other regulators. Please note, that I do not necessarily disagree with her, but instead have a deep respect for her as a professional.

Interview response twelve (CJO 2)

Name	CJO 2

Question	*Response*
General	
1	Consultant
Water Balance	
2	Water balance: Different for different sites. • Vegetation (in some cases make a difference but in others no)- if we quantified the impact to a wetland in its capture zone we look at vegetation pre- vs post and how much vegetation has been removed, how much infiltration has been forced or not, how much conveyance is happening. • Water balance to inform a water quality treatment sizing will be different. So it depends on project and context. • The water balance is a huge driver of the spatial planning for water. And it depends on what you try to proof: whether is a proper buffer, or working out on whether a working buffer should be so water balance becomes more important. **Remarks:** • Removing the vegetation results in increase recharge as water that was held in the root zone is not longer transpired. • Soakwell: yes. Also depends on the site. Clayed site with fill to meet Soil Class and then forced infiltration into the sand profile, then it will definitely change the water balance.

	• Fill: It should not make much difference but it depends on how you are accounting and the temporal nature of the water balance: annual water balance might not make any difference but it could change if looking at seasonal changes. We do not look closely to inter-seasonal changes. • Climate change: we have not considered CC in our water balances, no the numerical water balances per-say. However for the SW WA the prediction is lower rainfall volumes but more intense, so more intense rainfall, less infiltration, so will change the water balance slightly. We do not account for it or need to be assessed. We have not been required to assess CC. **Evidence:** Different for sites. Technical work ends in outcomes of some sort, such numerical. It allows the project to proceed. "The water balance is a way to quantify what an impact may be and then establishing a management response or development responses". It is hard to say if the water balance works". Approval of the work (by regulator) is probably the end for us as consultants.
Water Quality	
3	It depends on what you are going to do in the site and what it was there before hand. *It is not a straightforward question (it needs context).* Depends on the site: brown or in-fill sites. **Examples (Context dependent)** A 2 ha area surrounded by development and there has been an old school site, in this case it may be more affected by original groundwater quality rather to what is going in with the site. If it was an agricultural site or a farm that has dairy cattle on it, and the soil nutrient storage is huge and in this case if you are going to develop for urban, the inputs are going to be less but there is going to be legacy nutrients into consideration. If you develop in a bushland site with native vegetation and does not have surrounding influences and regional groundwater quality is low, and then you are proposing something that has a nutrient input then GW quality gets worse. <u>Nutrients:</u> "I would say that urban development typically will improve the situation". Urban development with BMPs in particular with the high density that is happening for most development sites, lots< 350m^2 and down to 150 m^2 there is no much opportunity to fertilize a garden. But again it depends on what you are putting there. If you put it in an agricultural site so you would probably not improve it, if you are clearing banksia woodland on permeable sands then so probably is the same input from POS. <u>ASS:</u> "For ASS that can range from nothing to a huge impact if it is not managed".

	If your sewer is above groundwater or a level (no dewatering needed) and that is probably at the lower point in your development, so no impact for ASS. Conversely, you may have highly permeable site that requires a lot of dewatering and very lower sewer depth (e.g., dewatering to -10 m) just because it has to go to a pump station to 7 m below water table. Sites at the coastline with high soil permeability could not be dewatered to install sewer pumping station. So, site has no impact to ASS because it could not be dewatered . **Evidence:** More than 150 water management plans but consultant indicated that there is a need to pick-up a specific site and talk about the issues there. Questionnaire too broad. (Examples of site locations/names were not provided)
4	N/A- Questionnaire too broad.
5	Perth just not embrace developing in clay but Class M, Class S or Class A (ideally). Bring sand to site then buyer will get dry feet. Water quality outcomes are high to capture (all goes into the ground) and we have projects where we monitor *subsoil outlets and their quality*, but "there is too much background noise in the sample to give a clear answer to whether the bio is working or not". Samples are from slotted pipes below the filter media. **Evidence:** The most recent examples are from the Perth South-eastern corridor, installed in sites with high groundwater and/or low permeability clay, there is still a measurement to fill the lot at the site.
6	We have been following FAWB guidelines to guide depth and specs for filter media, vegetation types but we do not set the lined- bioretention area (impervious area) having a filter media and the transitional layer and the subsoil drains. Most of them encourage infiltration to the surrounding soils which means "it is hard to maintain the saturated zone at the base of them, it depends on the site but most of them do not have their feet wet. We have stream lines (living streams) that are wet. Bioretentions are higher in the development in order to have a discharge point. They have a soil profile that can dry out or they have to have a proper discharge point.
7	We make sure they have at least clearance above groundwater from the invert so water will infiltrate and they will dry out. One of the key concern from the ultimate asset manager from LGAs is that they are inheriting systems that create mosquitoes habitat and that they can not get in and maintain because the soil is saturated (and that does happen, it did not to ours). Low permeability soils or low permeability layer built up on them inhibiting infiltration through them and the water can sit for quite a while but:

	Initially we will be very conservative in design: change our infiltration allowance to allow for proximity to groundwater and to allow for clogging (so we do not put too much load on it). We try to be conservative in sizing it in the first place. Design setting: the invert of it making sure to get clearance to groundwater. Typically, it is overall an economic driver to design and no water quality driver (consider position of bio and fill needed further upstream).
8	Definitely, it depends on the catchment size and different parameters that go in the sizing, *soil specification is the first* and that has a cost impact; bring in a soil that has all specs is very expensive (imported media @ \$120/m^3 for a basin(treatment) it does not take long to add six-figures to the cost!). If you spend too much in soils, it comes from somewhere else in the budget (e.g., affect POS/amenity). **Evidence:** Plenty of examples (different outcomes). What you see on the ground are not the outcomes of what the ideal design might be. So if you look at the outcome, you might say it is undersized for this catchment without knowing that there was a process and there are other influences: “You may get right sand soil, this much clearance to groundwater, permeability of this much, the catchment area works out all the things that you need for the bioretention for an area and that bio number 13A is that, and then very latter in the design process the local government says “I want a car park right there, because this is a rear block” so the bio ends at half. **Remarks:** The above is for all projects; there are always other influences, always other things than just what the hydrologists want to design and how we would like to design. You are always competing against the developer budget and the time lines for approval. Most of WSUD are UNLINED, there could be some lined but we have not built any. We usually encourage infiltration because it relates to assumption for the bio sizing.
9	“The biggest impediment is local government wiliness to take on board the maintenance requirements and to take something that is slightly different to the traditional”. That is the single biggest. LGAs are the asset managers at the end and because they are the ones saying “yes we will accept or will not” that is the biggest impediments. Sometimes we have the engineers at the early stages saying yes we support that “no problems” and it get through finals, that is the Civil engineers drawings got approved, you build it, you landscaped it, you managed for two years and then you have to handle it; the POS and the Parks guys say “no, we should not accept that POS ” because we will have to maintain it over time. So the biggest impediment to implementing WSUD is local government and their acceptance. **Remarks:**

	Water quality data: they are site specific and we have data but if there is no data we have plenty of guideline references that we can use and make conservative assumptions and we can design around that. To design WSUD elements sizing and hydraulic we use models, and design can change to meet different specs requirements that local government has. We do not have a tool here that is accepted and has a trigger for water quality or a guideline. DWER does not accept the use of MUSIC as they said is not suitable for Swan Coastal Plain. DWER developed their own tool called UNDO. The UNDO tool got limitations (it cannot account for groundwater nutrients, it does not allow you to generate the concentration targets that may come out of it, so it is like half a tool) and no one uses it. They created this awesome tool that does not have triggers for, and is no used and it is not needed in the approval process. At the moment, it will be better if we can size WSUDs to meet a target but there are all sized to what we consider to be arbitrary volume: "first 15 mm of runoff". And that has been contested recently and DWER refer that "we got research that shows that this is what it needs to be". So that is what Industry stuck with and it is frustrating.
Flood Risk	
10	Use an initial and continue loss model and sometimes an initial and proportional loss (XPSWMM as a main tool). This method does not specifically accommodate GW (as option) but we do account for that in our losses. Catchment can be broken up by land uses and land types but also into areas where we think no infiltration occurs and usually these are downstream or some stormwater feature (often give a clearance of < 0.5 m to groundwater and consider zero infiltration). It depends on the site. Methods that still people are using but they should not: rational methods based for catchment flows (there is a simple tool such as PCSUMP that some engineers use) they got context in conservative assumptions and in the right context are ok. But if it is flood modelling with floodplain, cross catchment conveyance, certainly a more sophisticated tool is needed.
11	We use constant loss conditions, we will use decaying water losses for treatment structures for the design of soakwell for instances (own loss decay model to simulate the infiltration rate under different head and soil clogging conditions). We use our model depending on the site and the budget constraints.
12	Typically, break up catchment by main land uses and to densities. If we model our structure plan for instance we may have one catchment area with roads and lots with low density (R20) medium (R40) and high (R80) densities and the road breaks down into verge and pavements (each with different loss rates) and within lots (roof, pave, back lot and front lot because they retain and behave differently) a bigger lot will let water out and route to the front and each of these will have different losses values. We may have 8 to 10 different losses regimes across the catchment and depending on the catchment.

	Routing is also differently: route roof water to soakwells (with size and decay rates but if storage exceeded is routed back into the system). In some cases no routing from backyard to the front (excluded from contributing runoff). Driveways are routed to road so it depends on the density of the site so typically 8-10 losses types in the catchment and then they may be 10-12 of those within the development. Infiltration from road and parking lots are given and initial and continuous loss but it is small (1-2 mm for initial and then 0.1 mm continuous).
13	We will force consideration for it to groundwater (GW) for flood modelling. We may route flow into or out of a structure to account for losses (it may be subsoil or something else). But typically, the duration that we are modelling is short (analysis from 20 min to 5 days events) for a critical duration for design. We model one catchment to work out critical duration and then use that critical duration as a design tool. If we do not use critical duration analysis then we use a 1 hr duration in design.
Groundwater Level	
14	It depends on the context and site configuration (e.g. channels or stream lines at the side or a retained flat site). Typically, close to GW and development on top, you bring fill in to achieve clearance, if no GW control is required and if it is a sandy site and it got a lot of infiltration anyway then it is not going to be a lot of change depending on how the road area routed. Clearing the land from vegetation and forcing infiltration through soakwells, then groundwater typically rises. But we will not usually do that we have some of control to make sure that it does not rise. Conservatively you bring more fill. **Evidence:** From bore data can be seen that groundwater sometimes will rise (stereotype of urbanization causing water table rise). Rise during construction may occur in site with low permeability underneath, with 1.5 m of fill without GW control, so water does not have anywhere to go and groundwater is going to rise.
15	More and more we see from client the desire to minimize fill and there are sites of low permeability, low grade soils, and quite flat as well. We assess this using MODFLOW (Visual MODFLOW) and use the DOW guidelines about what rainfall pattern do you use and what the clearance should be.
16	Pumping no. Open drains were used in some of our sites (swales) instead of slotted pipes. Again there was context for that and the reason was because the road side was quite flat and using road side swales allow us to place it flatter than a pipe network. It was agreed with LGA. In this case was more design for water conveyance that groundwater control. **Evidence:**

	Sites using open flow living stream (Armadale, WUWA areas living streams) and Park Avenue (preference to surface drainage than piped drainage). All sites got fill and subsoil pipes as well.
17	We always bring our soil cores and bore logs. We often either have previously installed bore logs or our own bores (installed). Geotech test pits (hundreds plus of test pits) are used so a pretty good idea of where the clay layer sits and what the different up grades are. **Remarks:** Regional soils maps are not used for modelling but for earlier stages in project. If we are modelling at any level of certainty, we need to make conservative assumptions (e.g., existing soils are sandy-clay and we have no test pit or anything like that) then we treat that as an impermeable layer and we will bring the fill on top with the specs and use that as the permeability of the fill in the model. In that basis, it is pretty conservative. We try to avoid overconservative assumptions because they cost money.
18	Source of infiltration responded above.
19	Depends on the site. If it is something simple we may use pre-development measured levels as a surrogate guide of what the future levels may be, so it is pretty basic. Usually the response is to bring more sand in. It is a pretty conservative approach. For prediction of level with more certainty we use numerical models.
20	Depends on soil types and the vegetation types (sparse or dense vegetation). Recharge could be anything between 40-60 % for pre-development or it could be as low as 20%, it depends on the site. Post development, it could be higher as 85-90% (but also up to 95%). **Remarks:** We may use information available from regional study with assumptions for recharge. Recharge estimated as percentage of rainfall (models use full rainfall time series 30 years, or you can use an average rainfall year or run the entire rainfall records or estimated from a prediction of what the annual pattern will be).
21	It is evolving in WA, we have a guideline probably from a year and a half that is still in the testing phase. The guideline was about that everyone has a consistent methodology to use in terms of recharge values. IPEWA guidelines for control groundwater and also establish what the clearance should be under different recurrence intervals.
Groundwater Levels risk	
22	Yes, mounding is expected between them and it depends on whether the utilities are set in relation to the mounding there could be interactions. The

	utilities themselves can also contribute depending on where they set and what they have constructed. **Evidence:** Sewer in an aggregated bed could also act as groundwater control depending on how it was graded. Relative position: subsoil higher than sewer with coarse aggregated to hold it nice and firmly could actually acts as a groundwater control as well. That is one of the potential interactions. "I have seen sites where the GW control were not working as they suppose to, and I think the civil contractor found the issue, it was localized soil grade variability of the fill and there were few areas where the fill has lower permeability and different degree of compaction and that caused localize mounding". The solution was to cut extra drainage (it is a Perth site but can not disclose location).
23	We do that numerically but not specifically modelling the interaction. We will give it a loss, even an storage area we will give it a loss (initial loss as well). We will reduce losses for storage and conveyance (also for a long conveyance corridor that got its own catchment) if they are close to groundwater. So we account for that in the loss values given to it.
Groundwater Levels Benefits	
24	Yes, it could be open channels instead of pipes. If you use open channel to control groundwater they will be seasonally wet (for 4 or 6 months of the year) and it has to be on an open space, low in relation to the lot elevation and surrounding land and it is going to be flat because groundwater control is generally flat. So, what you are going to create is a development that got a channel through the middle of it (with steep side because of space) and it is going to be wet and probably very slug-ish. "The LGA will hate it and getting an approval will be a nightmare." Vegetation theoretically could work (increase ET) if you do enough but we do not account for it. We do that anyway as part of the street scape and it depends on what the LGA want and what the developer wants.
Groundwater Quality	
25	Now we come to the early questions that can be related to legacy nutrients. Can we treat groundwater? We are now looking at and there is no a lot around to guide how you need to treat it. There are plenty of works on how to size treatment wetland for varies masses of nutrient, but there is not anything that talks about legacy nutrients at a given concentration on how to deal with them. We are testing few methodologies now and trying to get them approved, we seem to have some initial traction to the work but it is all theoretical. **Evidence:** • Sites are in Armadale area, with high legacy nutrients, and there are concerns on mobilizing legacy nutrients and entering waterways. In one

	instance there was a former piggery with pretty high nutrients. There are valid concerns. • There is a little bit of work, some of the Olga Baron works to talk about times to nutrient breakthrough in the WUWA area.
26	Yes, post development water quality, same example and we try to quantify based on drawdown and a set of assumptions on how quickly the groundwater may move and what mass of nutrient will be treated, to then sort and determine the treated area for it.
27	Impediments still will come back to the same issues of amenity, mosquitoes and maintenance, and LGA really will have a hesitation to accept them as their assets. If you give them an asset that they do not want to maintain, well of course it will end up full of algae, rubbish and sediments. They expect assets to be maintenance free (which it is not) and they openly tell us that they will not maintain them.
Surface Water Flows	
28	Typically, because you are bringing roof and road, the flow will increase, and we need to slow it down. If the site is close to groundwater, then it probably will have an outside discharge, because the site naturally discharges somewhere, and if we bring roof and road it will speed up and we need to slow it down. **Remarks:** Seasonal discharge levels, NO. The planning that we are doing is event based, unless that it discharges to a wetland (sensitive asset) that we need to determine the water balance for it and what the changes to the water balances may be. In that case we applied some numbers to it. **Evidence:** Yes, we have done some sites down in Armadale: CCW wetland, high groundwater, catchment under development with subsoils, legacy nutrients. Everything that we talk today is all in one site.
29	Localized treatment of some sort, minor event for treatments adds to the retention requirements, at lots we use infiltration, but if we do not have infiltration we have lot connection pits and they got a volume as well. Whatever is not pick up at the lot, in stormwater pipes and in the localized treatment; there will be a subsurface storage cell or flood detention (additional one at the end). We do not always account for the stormwater volume in the network and the time delay on the stormwater in the network, we usually take a catchment base approach but the civil engineers will do it. They account for those delays but they do have a conservative approach typically. We can account for it, we did in some projects, but it is expensive to do. **Evidence:** In the Armadale area we have some cases (all have the retention mentioned above) but the peak flow was allowed to increase. It was discussed and agreed with Water Corp, DWER and LG that the flow will increase so you are

	not going to be detaining. That is an unusual outcome (Wungong Urban Water Area).
30	If you have done the modelling at the structuring planning stage (broader planning stage), and it gets to subdivision detail design, UWMP, if the detail complies with LUWM we might not model it. It may be completely sized by the civil engineering team. We work on various approaches. Some times the design has changed and we need to re-model. Parameters for modelling (constant or not) depend on the density. If you have a single lot (350m^2) vs another site with 100 lots (all 350 m^2) we probably treat them the same. We keep the same for the lot catchment but then for the 100-lot site we will use spatially routing: links to the node all reflecting of the size of the catchment, and depending of the routing (surface base routing) we have all the characteristics of the surface channel, if it flows to a pipe network or links that have standard parameters (Manning's n, profiles, etc.) and that gives the right time lags without introducing inconsistences or instability. We allow for the 100 lot catchment to the different times that it takes to come to the site vs the small lot that has the same losses parameters but it has no conveyance parameters because the time is shorter. We account for that.
Surface Water Quality	
31	We will usually have pre-development data to understand what happens before you are going to do anything and use the pre-development data to develop trigger values, and your post development approach to work out what you trigger values should be. But because we have such arbitrary sizing treatment area (first 15 mm) to get it approve, really the pre-development trigger is to provide your baseline to see how you have changed things post development. If you got same locations, bores upstream and downstream of your POS, and predevelopment data then you can compare before and after. We usually have the pre development data to generate the trigger, then the post development will say you need to monitor the same location or consistent with, as some will have to be shuttled at bit, and then use the trigger value to work out whether you need to implement any contingency and that then feedbacks into the management of the site.
32	Based on monitoring. The UWMP will have a section on post development monitoring, and some times we will not propose any groundwater monitoring unless is a site with high groundwater. We monitor one representative POS area (among many), and if it breaches the trigger then: • Upstream-downstream comparison first thing to see if upstream is the cause. If downstream is higher then additional monitoring will be required. • Alternatively look at another POS to see if they have the same sort of things and then use the contingency plan (steps to take). At the end it may require to change the trigger because it was not what it was before. • If you have landscape in-house so you know and look at the specs on what nutrient was applied and check if you are applying too much nutrients,

	when was last application, can you change regime, or is the guy across the road just fertilizing the lawn (it is possible).
Harvesting and Managed Aquifer recharges	
33	Yes, same site, WUWA a living stream intersecting groundwater, it has a wet well at the base of it that extracts water (mix of surface and groundwater) but it is extracted from the surface, it feeds a storage underground subsurface and it is used to irrigate the site. This is harvesting no MAR. There is a site where MAR is considered. It has an old MAR scheme and it has been in the ground for a while. For other sites MAR typically refers to use of wastewater. Carlos suggestion on using infiltrated water: DWER does not consider infiltrated stormwater to be harvested. DWER will view it as the site already has infiltration and groundwater level will probably rise as a result of urbanization and if you are going to take out of the ground it will be licensed. DWER will say that their model always assume that there is infiltration on site and it allows us to generate an allocation and it is fully allocated, so you can not have any of it.
34	For the WUWA site in Armadale, harvesting is secure because it has a big catchment contributing surface and groundwater to the living stream, it is not intended as a groundwater harvesting approach but as a surface water but because we know it intersects groundwater is going to be both
35	Well MAR is just a storage device, yes it is an aquifer, yes it is a process but it is just whether you put it in a water tank or you can put it in an aquifer; it is just a different type of storage and different considerations. There are two questions here, managing aquifer recharge or harvesting surface water (or including subsurface water) and stored it in a deeper formation? Yes it could be done that but nobody does it. MAR is just a storage, and there is a whole approval process for that and assessment process, and it is pretty complex. It is not just a take over there and sticked into the aquifer like putting it into a tank. If you got an storage tank it will be straight forward but if you got an aquifer you need to test the characteristics, understanding the aquifer, other users, potentially there is a lot to it. The context to use MAR is where there is another source of water (like wastewater) and what do we do with all this water.
Development	
36	Alternative way to built. With different soil types yes, but not particularly with high groundwater. With high groundwater you still have to build road to get access, road pavement in high groundwater will not last very long. So my answer is no, I can not identify any.
37	Yes, there has been a case with subsoil drainage that was not properly connected and it did not work but then it was fixed. Contractor did not connect the pipes outlets to the main connection points and it was not because of the design. The early example due to differences in soil compaction only affected a couple of lots rather than the whole area.

General	
38	"Key impediments to get WSUD approval are Local Governments. That is the primary impediments". I would say that DWER encourages WSUD to be implemented but they are the opposite end of the spectrum with unrealistic expectations of what can and cannot be implemented. LG got a super conservative approach: • Do not want to do any differently because of the cost and the maintenance requirement for it, • What LG may inherent is a little be different and it does not work. While DWER aspirational on what it should be achieved but the two do not always line up. Both are part of the approval process because at the subdivision stage you usually get the Urban Water plan approved by LG in consultation with DWER. **Others:** All local governments are slightly different (Inconsistencies). One will accept one thing and the others will not. One got a standard detail that they can give it to you, the other ones do not.
39	Contested areas, yes, "first 15 mm criteria". That has been contested and risen by industry, engineers, hydrologists, and local governments are all questioning it, everyone is asking why is taking this arbitrary approach of 15 mm, what is it need to be 15 mm? "Surely 15 mm is not needed to wash a roof, what is the science behind 15 mm?" • We understand that the science said (it was a thing in the wind) that can get 95 % out of the pollutants. • That is probably a big contested area at the moment, in the last two years getting a lot of noise and the more local government we meet the more they are raising it. • It is inconsistent across all local governments some of them are pushing it, some are not and it is definitely contested and probably the biggest one at the moment. • It has an impact on the size of POS, the form of POS and if you got a site that is fully retain, all the catchment goes into a POS. **Others:** Another one recently contested and a critical one is **"***the actual storage achieved by the loss assumption in permeable fill".* You take an initial and continuous loss and applied over 12 hour events and you got a volume but DWER takes the position that "the number is too big". There are ok with the initial loss of 15 mm and continuous losses of 2 mm, but we think that 40 mm that results in losses is too much of the 100 mm rainfall. This is something that is evolving and being tested and if it becomes throughout this process the DWER development policy will change the all loss

	assumptions. Everywhere developments in Perth are in sand and it is all about permeability of fill. Carlos asked about clearance to GW: It was previously contested but the guidelines put something to look at and LGs say ok, so is there a guideline that indicates what the number should be. Some of them got their own guidelines (e.g., Armadale). They got their own guideline that they produce their clearance to GW below POS. Probably not the key one, I would say the 15 mm is the key one.
40	People to talk to: Jim Davies (JDA), Sasha Martens (H2O), Local governments: Mattew Tapscott (Armandale), Craid Wansbrough (Waneroo) People who disagree: Agni Bhandari and Terry Kefalianos (DEW).

Interview response thirteen (CJO 1)

Name	CJO 1

Question	*Response*
General	
1	Practitioner
Water Balance	
2	Effect of urbanization in water balance from the groundwater point of view is based on experience from sites and problems *that we see during construction process (design has yet not been implemented)*. Effects are: increase the shading decreases ET. All has a very measurable impact on the water balance. Groundwater rises significantly, not only in the winter months but through the year. That is evidence based and from numerical modelling (MODFLOW): • Increasing shading surfaces, putting soak well increasing recharge and you decrease ET, all have an impact from the scientific and assessment point of view. • Water table obviously rises a lot if subsoil drains are not implemented. • Subsoils flow more than traditionally expected even during the summer time. Anecdotally, Local Government (LG) people observed the same thing. Effects of urbanization on water balance in high groundwater areas are a *well agreed knowledge across our organization* and it was heavily influenced by findings and experienced by practitioners. It is also well known that recharge changes post-development. **Evidence**

	• Engineers on the field during constructions observed and reported water table increase of a couple of meters in places where subsoil drains were not yet installed. January water level higher than AAMGL in a sector of the development without subsoil drain. Sector with subsoil drain really works! • CRC sites at Whiteman Edge (Brabham) and Rivergums (Baldivis). LWMP docs. • Site in Harrisdale with 2.5 m fill above AAMGL with no groundwater control (sufficient clearance to GW) showed rise in water table of a couple of meters. Subsoil drainage was then required.
Water Quality	
3	Concentrations values for nutrients before development are "all over the place" ranging from 50 mg/L to 3 mg/L due to multiple processes (e.g. flushing). It also depends on the previous development status of the site (agriculture, industrial). Predominant now they are in green fields with previous agricultural site with high nutrient concentrations and highly variable. Post development concentrations still highly variable perhaps we have not monitored long enough, so they can be all over the place. But traditionally we will expect nutrient concentrations will decrease. • Subsoil waters are much cleaner: Phosphorus (P) down for all species, and Total nitrogen (TN) drops a bit. Nitrate does not move much (generally it is the issue it does not change). • Post development GW nutrient concentrations still variable, flushing when it rains and still high, it does not clean up straight away in the GW. GW post development is still high but we do not know if it is due to fertilizer (POS) or stored in the aquifer. It is still unknown. • It is recognised that subsoil water is a mixture of GW and runoff that goes in into the basins. Acid Sulphate Soil (ASS): post development pH still goes up. Upslope areas (high grounds) still kept the levels above 4 (upgradient) but within the development it definitely goes up. General trend for pollutant concentrations for post development: decrease after development due to increase in recharge. Overall concentrations decreased but unknown to what happens with loads. No load computation. Loads computation in progress via modelling. **Evidence** Concentration decreases as shown by data from Whiteman Edge and Rivergums. Subsoil water is much cleaner
4	As more recharge takes place concentrations are lower. The Whiteman Edge basins with limited vegetation and soils amendments showed low dissolved oxygen (DO) concentration, as the water hands around even longer just below ground ("... some sort of treatment as the bugs are doing something").

5	We have no evidence that biofilters are working from the water quality perspective as we do not sample subsoil outlet from the basins (basins refers to bioretention basin). Basins are working from hydrological point of view. We put subsoil under the WSUD to make sure that they are free flowing (no inundated) and operate in the same manner that if there is a much large GW clearance. Generally we will put always subsoil beneath the basin. In one of the sites, we were asked to dig out and fill a wetland and use a mixture of the pit soil and amended. Permeability tests were possible to conduct but under real conditions the water did not go, it just stays around. Situation experienced at two sites. We monitored subsoil outflows which are a mixture of stormwater and groundwater and the outflows come cleaner, but it is unclear how the WSUD is contributing (nutrient uptake by plants, etc. ("We have no evidence to suggest what processes clean up the water"). Much of the biofilters are under-vegetated (the ones that I have seen) and soils are really not amended. Original design may be changed later by engineers ("probably will do what they think it should be").
6	We try to follow the Payne et al. (2015) Guidelines for WSUD but those require more than what the Local Council (LGs) requires in term of the clearance, for example suggested clearance is between 750 to 800 mm, but the subsoil outlet point is a constraining factor in relation to fill for the rest of the development. • Yes, we will do it when we can but in areas of the development that are constrained by groundwater is not practically achievable. • The new IPWEA-WA guidelines for subdivisions recommended 300 mm clearance (from the bottom of the basin to the bottom of the biofilters material). • There is a discrepancy in the application of the rules between IPWEA and Payne et al. (2015) guidelines and a lot of the councils fought back to this (also DWER). • Spoke to engineers about proposed subsoil in U shape to comply with guidelines (achieve clearance) and engineers do not want to do that because it will clog in no time. On ground engineers are on site all time and they see staff (so it is the design engineer's risk) so they do not like to do things.
7	Always consider GW in WSUD design. However design just only considers rainfall from above but it does not consider groundwater pressure from below. We were asked this question on what would the groundwater do: will regional GW come up? Automatically you will respond there will be no problem but we do not know. Sites without rainfall for a long time show subsoil still flowing, so it seems no to make much sense. There are more aspects of the groundwater that we need to know more about.
8	Fill is the main issue for the Perth southern-corridor. Sourced fill is not loamy but has decent PRI (phosphorus retention index). Sand (Spearwood) from two

	sites locally sourced has PRI of hundreds (up to 750). We found that we can comply with locally sourced material. • Particle size analysis indicated sandy material (no loam) and high PRI could be related also to iron-oxides to which P attaches (other than clay content). • All WSUD "are unlined" except for one site where we harvested that water. "We do not know any lined WSUD". • One thing discussed with some councils (i.e., Armadale) was the need of a 30 cm wide hard bottom surface in the central path of conveyance swales (for water treatment) to prevent overgrow vegetation roots to push/crash underneath subsoil pipes.
9	Impediment is the council preference: "preference for WSUD is hampered by council preference for maintenance and there is not consistency across councils in our experience in WA". No issue with methods for water quality. UNDO tool (DWER WA) is used although it is a very generic tool and you get the water better (a model that you can manipulate). • Other issues: • Inconsistency in design because is related to preferences (particular Officer, Maintenance Officer or Approval Officer). • Inconsistency in methods: 3D modelling for subsoils used but councils are very strict on what you need to do (regardless of the methodologies). Other councils accept work from consultants using simple computations for mounding. There is no consistency in methodologies, which is quite frustrating. • The LG will set the design parameters not necessarily DWER. LGA has the power and WSUD and management of water quality into receiving environments is determined by LG and not necessarily by DWER or Water Corp, Peel Main drain and estuaries. They can influence but ultimately the council has the decision. **Examples:** In one site in Baldivis (City of Rockingham) a project championing WSUDs (stream line full of WSUD elements) was replaced by a simple underground pipe due to opposition from council maintenance and landscape officers. DWER requires conveyance swales (no pipes) and having a natural flow open system (advocating) but council approach was less maintenance and turfed areas (1A6) that potentially can result in more nutrients going to waterways. At the end of the day, district water management strategies (UWMS), LWMS and Urban water management plan (UWMP) are technically approved by the WA Planning Commission but they are un-advised by the Local Government.
Flood Risk	

10	Flow computation using 1-D model (XPSWMM) but without SW-GW interaction model. Groundwater model results are used to set conditions for XPSWMM. Losses and infiltration rates are based on geotechnical info and GW clearances and baseflow conditions to surface drainage are input parameters to flood modelling. • Infiltration in a basin with high water table: Infiltration in sand for design would be 5 m/day but it is reduced if water table is high. • Infiltration algorithm embedded in XPSWMM used for event losses. For a small development it can be adapted. Initial and continuous losses accounted, as 0.5-1 m clearance exists due to subsoil. • Event durations for peak flow computation vary from 2hrs (small subdivision) to 6hrs (large subdivision). • GW rise will be not so rapidly over the event duration and it is not considered in the model at subdivision scale. We see no need to account for the process at subdivision scale modelling (60 ha) but it could be needed for large scale modelling (e.g., MikeShe used in the past). At subdivision scale model you will always have continuous losses due to GW control system.
11	Conditions for the 100 yr-ARI event: control groundwater level, wet year, and the main assumption focused on outlet wet conditions at the receiving water (wetland, drain network, estuary). Outlet into estuary and large drain consider tail water conditions. Losses constant over time according to model and assumed to be rapid.
12	Sources of infiltration: Percentage based on what you see. POS and runoff coefficient, lot density greater than 300 m^2 assign runoff coefficients which are percentage based. No infiltration from impervious area is considered. For typical subdivision we take 0.7 as runoff from a road reserve as it is not all pavements (edges).
13	Receiving environment conditions takes into account GW interaction
Groundwater Level	
14	Always it goes up. See below for evidence.
15	Estimated quantitatively via 3D modelling. First pre-development condition for calibration and then increase recharge rate to 60-70 % (conservative). If uncertainties with climate change (assume an increase in rainfall rather than decrease) subsoil will positively respond to the change. If 1 m clearance to AAMGL and you do not put subsoils, in 10 year time groundwater may rise 0.5

	m. Control by subsoils is like an insurance policy for unpredicted possible climate change conditions.
16	Measurements to control GW: subsoils drain, open drain in rural settings and imported fill. Never pumping as it is not a long term solution for residential (internationally accepted but not by local councils). **Evidence:** • Use of subsoil drains and fill evidence from field. All sites above mentioned. • In Harrisdale development without GW control and 2.5 m of fill above the measured AAMGL, resulted in water table rise and the solution was to retrofit with subsoil drains. • Learnings: "Imported fill is a way to achieve geotechnical classification but it is not a way to control groundwater levels."
17	Source of information: "We use geotech reports, layers introduced into 3D models (1D approach misrepresents profile). The geotech models are done earlier in the studies as engineers need to quantified costs (done before consultants get into the job)". Then information from installation of groundwater monitoring network to get: groundwater level and water quality. Info needed to quantify aquifer parameters, depth of confining layer, etc. No, we would not use soil maps (only as a reference for overall settings). Soil parameters are from geotech reports. They provide infiltration capacity, particle size analysis, and clearance to GW and good spatial coverage. Information then used to create a 3D map to input into groundwater model. Regional available information (other bores log) can be used for cross-checking. Surface soil mapping is not accurate enough. Best info is physical site evidence (Geotech reports). Data collection also during bore drilling for monitoring (log records) using sonic and push core
18	Similar to 12
19	Numerical modelling- 3D MODFLOW.
20	Recharge rates are estimated for pre-development using data available and calibration of 3D groundwater model (15% value or less as developments are often in discharge zones). For post-development we work on 60-70% of rainfall total (monthly stress periods). The limitation of this is recognized because it is linear. Vertical flux model estimations by Silberstein and Wu (2009) recommended 50% for urban and 63% for industrial. High density housings are close to industrial. The recharge assumes a high rainfall year. No interest in 5hr event but seasonal or long term response. **Remarks:** • No aware of values for recharge by industry as we cannot see other people reports. One study used 35% for both pre and post development (seem to be low), but we do not see other people reports, so no aware of values used by industry.

	• The Baron' study for Serpentine area (refers to Baron et al., 2013) uses recharge of about 50% mark, but we use a little be more and it does not change results substantially (as subsoils are in). Our estimates are conservative.
21	Industry point of view is No. Separation of subsoil by recent guidelines suggested that it can be done by 1D analysis. We do not believe that it is appropriate. We are still using 3D computer models but still we do not how good they are because we have not enough measurements. Our involvement in the CRC project is to obtain comprehensive data set to test models. Only then we can know what is really happening **Remarks:** • " This is absolutely an area of contested knowledge. Consultants not using 3-D modelling will indicate no need for them. We are expecting results from our data collection to test 60-70% recharge rate values. Also investigate assumed linear dependence of recharge rates from rainfall".
Groundwater Levels risk	
22	Not sure about this. Generally, subsoils are a little bit deeper than utilities; they might interact with sewer as they are much deeper. Subsoil is your cone of depression and utilities pipes should be dry. **Evidence:** We do not have any evidence that suggest it is working any differently.
23	Yes, depending on the local government. We consider groundwater interaction during the ARI flood design process as baseflow component (e.g., 30 cm of water as estimation).
Groundwater Levels Benefits	
24	Separation guideline is moving in that direction where they are trying the phreatic line to be between subsoil drainage. Some LGAs say at 1 m others at 0.8 m and then ask industry to agree in how close to the surface ground can that line be. "That is a step forward, it reduces fill that makes the approach more sustainable. But it will all come down to the geotechnical classification and by proxy all will come down to the build form". The development industry (builders) acceptance and whether they will accept that they do not longer have a 1 m clearance for the pad that can built on top of that. Can the clearance be less than 1.2 m? **Remarks:** • Working mostly in WA, we have not come across other examples as it is business as usual here: flat lot, 350 m^2 to 500 m^2, bricks and tiles. "It will take the building industry to respond to the pressure that is at the other side".

	• We should be dropping "control water levels as it is not a matter in an urban development" and it is only if there is a GW dependent ecosystem around. Reducing fill represents millions of dollars and increases affordability. Of course you are creating more flow but it can be redirected to an appropriate environmental sensitive place; "DWER said is not concerned about AAMGL or your CGL is but in practical they always do". • It is known that in Holland they have a series of open drains. • Carlos suggestion of tree belts (similar to deal with salinity problem): • Yes, trees can pump water but we have not seen such approach here. It requires other issues to consider: • Where to put them? a typical subdivision now there are quite dense, the roads are narrow, you have subsoil in one side and utilities in the other side, in the road reserve is actually no room to put tree in the lots, unless the developer decided that you are going to have a 25 m reserve road and create a green belt in the site but traditional subdivisions (Cities of Armadale, Gosnells and Swan) have a 17 m road reserve and there is no room for a tree line. • Do you mandate the tree? You cannot mandate tree in someone's property and new subdivisions are 350m^2 block with up to 75% cover surface. • Putting tree could be good to improve water quality. City of Stirling mandates tree retention and the tree growing policy in new developments to improve urban cooling and social amenity and it will take LGAs to take the initiative but a lot of them do not have the resources to do it.
Groundwater Quality	
25	Methods for groundwater treatment are simple amended soil in subsoil drains, plants in the basins, but not sure how well they work. Groundwater treatment is done by collecting and conveying it to a basin with amended soil. This is the way we do it but there is no other groundwater treatment method. It is just a treatment at the outlet discharge.
26	Post development via monitoring. Comparison with water quality data from pre-development.
27	No issue here.
Surface Water Flows	
28	We do not measure flows. Modelling suggests that imperviousness creates rapid flow (flashy) but not measurement of flow pre- post development. **Evidence:** No evidence for WA based on data but modelling. Theoretical urban water models. Common and agreed knowledge based on literature.
29	Biofiltration basins and flood retention areas. Wetland with control outlet, pipes to holds flow underground. We have constrains on flow rates after development. We have bioretention and flood storage everywhere in new

	developments that are adjacent to a wetland or a drain that has flood study with prescribed flow discharge. Only a couple of developments where we only have bioretention basins and we were able to discharge to receiving environment that has not flood risk levels, where we can push everything else beyond the 15 mm, but the majority has to have managed outlet. **Evidence:** Reports are submitted to LGA and DWER.
30	Flow based on runoff coefficients. Lot sizes and density (e.g. R60) runoff coefficients will be applied across the catchment based on percentage coverage.
Surface Water Quality	
31	Biofiltration basin and conveyance swales. Refer to question 5.
32	Assessment of performance only as part of the post development based on monitoring activities (water samples for subsoil drain and surface water). No tools for post-development assessment. **Remarks:** UNDO tools to check performance for design. Then we submit the reports and we do not get feedback or comments. Collected data is not used to re-run UNDO for testing or comparison. It is not the focus of the local government.
Harvesting and Managed Aquifer recharges	
33	Yes. Conditions are related to water allocation for POS. If there is not allocation then we recommended it. We identify and advise client if there is a need (no allocation for the area) and suggest them how MAR can be done. “MAR is very an expensive process and guidelines require a pilot study, drill a hole, check the quality, do monitoring so it is not in the interest of the property developers of the shareholders in spending money on an academic exercise. So unless there is a driver to do that, which is “not allocation”. It should be a government lead job unless there is a need to do that.”
34	We look at the treatment, at the sources, at the site, inter-annual variability but it will come to a cost. If there is no option (water allocation) developers go into it. As consultant we advocate for that in some projects on the Perth north-east corridor where there is no groundwater allocation left. We are leaning *towards harvesting and discharge and not strictly MAR in the technical sense* (aquifer storage and recovery) yet. We recommended several options: first is direct subsoil drain harvesting and that is direct use of subsoil for irrigation. Only if there is scientific evidence that harvesting is ok and enough water and there is future need, we will recharge the water and ask later somebody to pay to pull it out. “Industry should lead direct harvesting and government should lead MAR and recovery.”

	For POS, it is a better option than treated wastewater, the quality is much better than treated wastewater. Capital expenditure and ongoing operation for harvesting subsoil are much less that the one needed for wastewater treatment. **Evidence:** Study cases at Whiteman Edge and Rivergums.
35	Water harvesting from subsoils it is a management option, whether you capture that discharge or let it go into a wetland it does not really matter as it achieves the same outcomes of managing groundwater levels. "It is definitely a local scale solution" to water shortage. DWER are really interested in this way as well as industry as practical solution (and to some extend innovative approach).
Development	
36	No in the area of expertise.
37	No in the area of expertise about building. **Remarks** The geotech classification S, N, or A class the builder will indicate 5k or 10K cost for building to reinforce the pad depending on Class. The developers may be scared of the differences in cost with nearby developments for the same size block. The A-class is the preferable option and they look at all conditions needed to achieve it. This is driven by the builders. Everybody wants to be A-class because they want to be in even plain field. "The industry and the construction methodology are getting away from the consumer paying for a A-class (developers are taking the extra cost to avoid fill cost)".
General	
38	Universally accepted clearance to groundwater for the finished lot level" and "the overall philosophy in Perth of sand and soak wells in areas that are constrained by high groundwater". If we are going to control groundwater levels and reduce the importation of fill which makes houses more affordable and we reduce clearance, should be we looking at soakwells? Should we be looking at traditional soakwells? Linear soackwells? no soakwells and making the POS bigger for more storage and retention areas and not having soakwells retaining at lots? Then there are conflicting philosophies between local government and the DWER which is infiltration at source and sometimes infiltration at source is not the best in most standard locals. **Remarks:** • "The key impediment is the acceptance, the criteria that councils will accept on what is the acceptable clearance to control groundwater level or the phreatic surface at the back of the lot." • Some councils (e.g., Swan) sign up to separation guidelines but direction from the city's officers is that there has to be a separation of 1.2 m

	clearance to control groundwater levels and that is contrary to what they sign up to separation guidelines. • Inconsistencies across Councils then means inconsistencies across property developments which will translate into inconsistencies in the price of the lots because the filling is by different officers, and it is the officer levels that made that decision. That is a key impediment for WSUDs projects. Councils are protecting themselves from future pay work. • There are conflicting philosophies: if you are for at source infiltration you have to have more fill. Dropping the CGL is important because you can drop your fill, you can decrease fill but still having clearance because you drop the water level, as long you can protect any groundwater dependent ecosystem we should be able to do what we think is the best in most standard locals. **Evidence for conflicting philosophies** A couple of projects were DWER are asking for swales, raingardens; raingardens are really expensive to build and at the end of the day the consumers are going to be paying for them (problem for house affordability). Industry philosophy is that we collect the water and conveys it 500 m to a basin and the 15 mm rain goes into treatment and goes over top to a CCW (core conservation wetland) where treated water is required (it is not required in the groundwater 500 m away); we do not need a road side swale as the road reserve has to be bigger the lot gets more expensive. The buyer will pay extra for the green fill and removing road media infiltration increases lot number and makes house more affordable. It is contrary to DWER position which is not always based on science and that is the frustration. “It is a philosophy and not science and that is an impeditive, it is a difficult one”.
39	Answered Before
40	You should speak to: • Council officers: Damian Slack (City of Rockingham). • DWER: Antonietta Torre, Joel Hall. Disagree with you: AAMGL and CGL are critical and contested. • DWER: Jim Mackintosh.

Interview response fourteen (CJO 4)

Name	CJO 4

Question	*Response*
General	

<table>
<tr><td>1</td><td>Water management: planning- related to consultants</td></tr>
<tr><td colspan="2">Water Balance</td></tr>
<tr><td>2</td><td>Water balance: It was about the water balance and what would be the impact of urbanization with the loss of transpiration and the increase of impervious surfaces.

• The net result of that was suggesting that urbanization effectively elevates the groundwater (rise), because the loss of transpiration.

• The reduction in the shallow groundwater depth could have an adverse impact on buildings (e.g. in the case that groundwater has 8000 mg/L of TDS).

Under the above conditions, assessment of WSUD scenarios is important and then discourages infiltration systems.

• Typically, the interviewee deals with shallow groundwater where it is salty or contaminated. Concerned with not rising it or not moving it, so similar to Fisherman Bend (Melbourne) where the shallow groundwater is known to be contaminated and it is about not encouraging mobility of the groundwater table. Fisherman Bend is a brown-field development while Officer is a green-field.

Evidences:
SKM report: Chris McAuley. Assessing the impact of urban development on groundwater discharge to waterways- Berwick/Pakenham corridor. Final Report. March 2005. Also see Fisherman Bend (Melbourne)
https://www.wsaa.asn.au/sites/default/files/publication/download/Case%20study%2015%20Fishermans%20Bend.pdf</td></tr>
<tr><td colspan="2">Water Quality</td></tr>
<tr><td>3</td><td>Water quality: What happens as a result of development? Yes, the increase of the surface water runoff because of lack of filtration impacted soils (the filtration is impacted). The soils access (what the interviewee called) a slow sand filter or biological filter, which will improve water quality as water moves through generally, unless the ground is contaminated in which case controlled infiltration is use to avoid groundwater levels rise.

Evidences: N/A</td></tr>
<tr><td>4</td><td>N/A</td></tr>
<tr><td>5</td><td>N/A. No his area of expertise, he cannot tell how they are performing. In his experience with wastewater treatment with trickling filters and slow sand filters he would expect from them to progressively treating the water, but he cannot say the magnitude of that.

It is expected that they will provide treatment even as if they are acting as filter (not as biological treatment) because the water passing through drowning a number of pollutants. Net response to question is a filtration-biological media operating like a treatment (like it is done in sewage treatment) and then slow sand filters (as per water treatment).</td></tr>
</table>

6	Yes, certainly Melbourne has guidelines in regards to WSUDs and the requirement of the MUSIC modelling, but he doesn't know how well the things are followed.
7	WSUD installation in shallow groundwater: WSUD pushing water into the ground, so yes there will be interaction. Infiltration trenches which nature is to push water into the ground result in interaction by: • Increasing the volume of water into the ground and it rises the groundwater and, • If you got transpiration high systems (or increase flora and fauna) they will draw more water from the ground which also has interactions, so yes they have impact. Shallow groundwater in the cases that he works with is not up to 5 m depth but generally up to 2 m. To avoid interactions impermeable liners on your infiltration trenches and other things (or for trickling systems or going through the trenches for treatment) are used but actually drawing the water away. But for systems directly designed to allow water to go out into the soil, then liners create an impervious barrier to avoid recharge. Draining the water using a pipe at the bottom that is infiltrating at the top and then draining it away.
8	Yes, that is some examples of what they look into for Officer (Shire of Cardinia, Vic) and Fisherman Bend. It is not about media designing but more about how do they reduce the infiltration impact. **Evidences** Project above.
9	Impediments: "From my point of view the answer is yes and it is the understanding of the interaction between groundwater and the WSUD". There is real inconsistency of a natural root to a managed root in the regulatory situation. • For a WSUD that **"happens to recharge"** the groundwater that is ok because the regulator will not get involved. • However, for a WSUD "**that is plan to recharge"** the groundwater, then a full regulatory environment comes into place, which is the MAR type of situation or shallow aquifer recharge. So he got situations where he can catch storm water systems, catch the drainage or have a wetland which leaks and it recharges groundwater and that is ALL FINE. However if he designs a wetland for specific recharge, he will have to treat that water through a mechanical process as well, and that will not be ok and it results in a bunch of regulations to deal with. "I don't think the regulator understands the quality of water or the management and treatment of groundwater through WSUD or the water that goes to the groundwater, so the regulator will say I want to have a proved treatment system".

	For example one area is at Stant Bell area which is upon up Heffer or Heath Hill (one of their office department work). It is sand mining area with shallow-quite good aquifer and drain through some market garden. Market gardens can pump out of the aquifer and put it onto their vegetables and that aquifer is feed by urban drainages (by leakage from drains). However, if filling the sand mine with drainage water to allow recharge the aquifer, and then it needs treatment. There will be restrictions of what could be within the aquifer. So there is a real inconsistency on the natural processes that happen and if wanted to be done in a managed way. A whole of regulation will come into place, which are impediments to it.
Flood Risk	
10	N/A
11	N/A
12	N/A
13	No. He looks into results of flood modelling and as far he is aware there is not a lot of underlying assumptions about the filling up of the soil profiles other than between the 1:5 and 1:100 event; other than changes in the level of coefficient of runoff (which implicitly has an assumption) but it is actually a sophisticated analysis of where the groundwater is, and he does not believe that happens. But he is not a flood modeller. Flood analysis is all using model which could be simplistic one as MUSIC or by ROB model
Groundwater Level	
14	It can rise but it depends on how do you deal with permeability and the loss of transpiration so that is in the water balance. Most of his understanding comes from the SKM work (refer to evidence in question 2).
15	If you are trying to work with managing adverse impact that is when you need to have an understanding quantitatively. They did for Officer area work to inform the work and a quantitated model for it was done.
16	Yes, it was basically controlling the level of infiltration, encouraging transpiration and transportation of water away to minimise the recharge basically. No look at drawing water levels by pumping and taking that water away. He does not have evidences to support that it works. Testing has been done by modelling but no data to prove it. It was a theoretical exercise and with very limited knowledge.
17	N/A
18	N/A
19	N/A

20	No aware of any values. At the moment in Victoria they cannot increase groundwater levels by creating infiltration. Only injecting water into a quality aquifer can be done by putting a pressure water bubble into a salty aquifer. There is a need for it? Yes, there is a big need for it. It would enable people in kept aquifers where recharge is not allowed. He can create systems with more water into the aquifer that can be utilized and he can capture that value of that water as a right, adding a value to help and pay for those works. It will lead subsequently and help to pay for the infrastructure or the work and operation of the recharge system which may have downstream beneficial impacts to the environment.
21	N/A
Groundwater Levels risk	
22	Yes, he thinks there is a real risk but not sure how you can do it. It could be because: • Loss of transpiration and the removal of water (the all thing of knocking down the trees) will cause groundwater rise which happens in the urbanization. • Roof drainage systems that actively push water through the ground, or • Trying to retard on site to reduce peaking issues but actually creating more water into the ground and it is likely to push it up and potentially damage foundations or road infrastructure. • Salt resistance concrete of something like that (if high salty groundwater) will be needed.
23	N/A
Groundwater Levels Benefits	
24	Yes, it is a potential storage or water between the seasons, a balancing stormwater resource that can then be tapped and support the urban environment and POS. There is a lot of potential. • For a good quality aquifer, adding more stormwater increases the resource that can be tapped by trees, community growing up irrigation, and it also reduces peaking and streamflow. • For poor water quality aquifer: drains were used to draw down the saline aquifer wetland. • Suggestion on using tree belts to control groundwater: agree that the trees can be used to control groundwater (for good quality). Your street trees, POS areas and streetscapes are probably the core areas. Private open space is decreasing as the proportion of the property that people built on has increased. **Examples** Poor quality water (such as Fisherman Bend) we try not to move it, just maintained it. In Officer basically is saline, you might drain a little bit but it will also rise because tree clearing.

	For Fisherman Bend: natural attenuation of 500 ha of ASS sit mixed with a long history of contamination? It is pretty much "cap it and leave it alone". By sitting there does get slowly down.
Groundwater Quality	
25	Doesn't know how effective they are. But looking at treatment systems (refers to traditional system used by interviewee), filtration tends to remove pollutants from the environments, allows the biological use of nitrogen. It makes sense that filtering through soils (e.g. in the groundwater) will improve the quality of the water. No monitoring evidences of that, other than available data on trickling filters and slow sand filters (literature) and the water quality that they produce. Not aware of anything in the field of hydrogeology.
26	Fisherman Bend has a couple of reports looking at groundwater (commissioned by EPA). Water samples for FB represent current groundwater status because it has been developed for 150 years. There is not pre-development conditions as it was a swamp area. • Metals cntents, hydrocarbons, and things like that. No model used for it but based on data. • Sophisticated model (Plume model) or monitoring from the Alterna Petrochemical area in Melbourne (interviewee saw previous work by Parsons Brinckerhoff for the industrial area). • Yes, Officer is an example for salinity areas. Most of western Melbourne which has on basaltic clay has shallow saline groundwater.
27	N/A
Surface Water Flows	
28	Yes, hydrograph peak due to impervious areas, baseflow drops, so you basically lose the water much quickly. **Evidences** The Dobsons Creek work in Melbourne (data). Melbourne Water to access streamflow data (Chris Chesterfield). https://www.stormwater.asn.au/images/Conference_Papers/Stormwater12/Prosser_Toby_and_Catchlove_Rob_et_al_-_Non_Refereed_Paper.pdf
29	WSUD elements in Melbourne and planning control to households to not increase outflows. It is done via rain tanks and infiltration systems. Yes, common knowledge.
30	N/A
Surface Water Quality	
31	N/A

32	WSUD and MUSIC (Tony was champion of it, and adopted by Melbourne Water). Model used for assessment of new developments to achieve the water quality targets
Harvesting and Managed Aquifer recharges	
33	Yes, interviewee has looked at it and likes to try it in a couple of sites. However the regulatory challenge probably will make difficult to do it. Proposed to do it by a collection facility that actively manages aquifer recharge (a lot of regulation but it is not for a leaking retarding basin or wetland). There are a couple of sites to try and get credit for it, but at the moment he has not pursue those. WA got more experience with groundwater than Victoria and will be interested in how it goes in WA.
34	For successful MAR, interviewee indicates the need for: • Have a concrete drain. • A storage facility to allow to infiltrate in. • A regulatory situation that actually allows to do that. • A method to capture the quantum of water or extra water put into the aquifer, and • Achieve and get a revenue profit. Change in the capping of the aquifer. Creating an entitlement that can be sold.
35	View of interviewee: “MARs is a way to make stormwater recycling viable” because: • It gives you storage, • It always kills stormwater (stormwater availability: a lot of water when it rains but nothing when it is dry) • Costly to build storage above the ground but aquifer storage makes a lot of sense, • Also much less losses. Storage underground facilities: One place at the moment where it can be done, the Mt. Morton Lake system with a fresh water bubble on a deep saline aquifer but it is expensive (difficult to maintain). Better to do it in a shallow system where available. Users should be paying to extract the water back. Is the council using it or householders are using it? Just meter the bore. If the developers are paying $2-$3 per KL from drinking water supply, stormwater drainage systems can provide water for $1/KL, probably their attitude is that this is groundwater underneath my property which it does not cost me anything. This is probably the sort of situation in Perth where people do not pay for groundwater they tap out (The issue is willingness to pay if you create new allocations).

	Further remarks/issues: What do I have to clean it up when it is happening anyways? • It is rainwater that fall into the ground. • If development happens in areas with high nutrients (legacy) you can still use that groundwater for irrigation. "One of the key things that I have is the comparison of what is natural recharge and its water quality that goes in relative to the managed recharge because the regulation is very very different." • Natural refers to leaking drains or wetlands or retarding basins which are doing the recharge (uncontrolled). • Putting a lot of constrains into recharge: why are we not making sure that both things do not leak or vice versa? There is inconsistency of a quasi-natural recharge (allow with little regulation) compared to a scheme that managed recharge. **Evidence:** MAR also considers wastewater as source of water. SEW has one MARs scheme that is going into a "salt bubble", west of Melbourne, Mt. Morton Lake systems, a fresh water bubble in a salty aquifer. It will require to comply with regulatory framework. • What is the level of treatment that we actually achieve going through a soil mat of the groundwater or different sort of soil? Not credit for that has been given. • Interested on experiences in the US where they inject in one spot and then drawn it out in another spot and actually used for drinking. Similar approaches in WA in some of the schemes. • Research on what is the level of treatment that the actually aquifer provides as a slow sand filter could be an important thing to understand. • And if the water travels in an aquifer of a certain type such as sand aquifer of 100 m or per 1 km, how much treatment can it be achieved? How much load removal can it be obtained?
Development	
36	Yes. Aware of salt resistant foundation requirements, different sort of concrete, in areas of high saline water table. It is doing through the planning and building regulation: you put an overlay before you built. Yes, it could be the piling systems and all of that but the mechanism to do it is to put through your planning and building regulation.
37	Does not know (in relation to planning and building). Does not know how Mt. Morton lake system is working.
General	

38	In interviewee experience in Melbourne it is rarely considered. Melbourne does not use groundwater and it is only marginally considered in the integrated urban water management (IUWM) project. • If it is of poor quality: regarded as a risk • If it is of reasonable quality: regarded as a potential opportunity to tapped it • Drawing the water resources for alternative water usage or MAR: the regulation becomes a constrain.
39	Contested areas results from lack of understanding of it and you get different views with very little evidences" • Lack of understanding in the groundwater to stormwater and to the urban development impact. • There is little understanding of it because there is little evidence. • Essentially, a lot of this questionnaire here: • What is the interface of the stormwater to groundwater in an urban system? • What is the change and benefit of the development on the groundwater water table cycle, • Answers: We do not know! Essentially is the lack of knowledge. • "Certainly is something to be contested because nobody knows it"
40	People to interview: Muthu Muthukaruppan currently at Jacobs (he was an integrated water managers at City of Westwater) and he running now the groundwater group at JACOBS in Melbourne, he was the champion in MAR and stormwater schemes in the City of Westwater. Richard Evans (Formerly at SKM) guru of groundwater in Victoria.

Interview response fifteen (CJO 3)

Name CJO 3

Question	*Response*
General	
1	Practitioner - Reviewer – Regulator
Water Balance	
2	Water balance: you significantly change the water balance, putting drainage you got another source of discharge from your groundwater systems, and as you start building infrastructure (houses, road, etc.) you are tending to change the dynamics of the whole water balance.

	• The fact you are getting more of summer recharge that you would it have historically due to retained irrigation flows, especially if your source of water is portable. • Additional leakages from main water system and if you got unpressured sewer system, there is an opportunity for groundwater input to the old sewer pipes (tile or clay drainage pipes). • Yes, increase recharge overall in winter and summer because you are taking away the vegetation and people tending in summer to watering grass and gardens. If you have large blocks you are going to potentially increase recharge in summer months. • Yes, also potential to increase discharge where you got drains installed to manage your water table to prevent water logging or other sources of drainage infrastructure and that of course increase discharge. • Climate change impact is a tough one, predictions are to get a rough 7-10 % decline in annual rainfall but everybody agrees that we are going to get increase episodic storm events and again impact depending on your soil types. If you look at WA for example (Swan Coastal Plain) heavy rainfall events, you are going to get more potential for surface ponding and rapid infiltration. But in other parts of the country for episodic events, you will get more dry periods in between events and you are not going to have the soil moisture content to promote a recharge event. Yes, it is a very complex question to answer. • Removal of vegetation: you lose the potential for evapotranspiration and opportunity for vegetation to take up some of the water. **Evidences** No particular report/cases provided – Based on professional experience
Water Quality	
3	Water quality: yes. In general with nutrients: • Nitrogen: we got a lot of evidences that nitrate increases where you got heavy concentrations typical of cattle-farms areas and the depth to water table relatively shallow. The nutrient loading is too heavy to give opportunity for soil-aquifer treatment through micro-biological activity and that tends to increase nutrient loading to the water table. • Phosphorus: we have seen significantly more P spreading at the ground surfaces and they can leach to groundwater or been washed to waterways. Depending on their concentration and how heavily applied obviously they impact significantly in the groundwater systems. As the groundwater rises (typically it will do) the increase of urbanization and then clearance, yes the depth of the water is significantly shallower so the path for those nutrients to get to groundwater is significantly reduced. • Other pollutants much the same. ASS, typically you will see some flux again where your soil may dry out a little bit and keep your water table relatively low, and as it raises you will have issues and reactivating those ASS. It is going to be cases with continuous wetting-drying between summer and winter so you reactivate these ASS soils. So strategies will be

	required to prevent reactivation and they need to be incorporate in any planning and design and building systems. **Evidences:** For the water balance, here in Adelaide with a shallow groundwater system in a sandy dune based system. In the Lefevre Peninsula (SA), there is an urbanized area different from others areas in SA and more like the ones in WA Swan Coastal Plain.
4	No really evidences. High loading of nutrients such some of the work that we are doing over in NZ on loading into the groundwater systems which exceeded the 12 mg/L (as high as 30 mg/L) nitrate concentration. Mostly in dairy farms but I have not looked closely at nutrient loading in urban areas that is accelerating due to people doing their gardens and vegies patches, etc. It is an area that I am not aware of or look in a great deal of details. Do you need to quantify impact of water balance and nutrient loading? If it is a large scale new urban development, that is typically done. There is not a lot on the scene of what you guys are doing in WA and in other areas in terms of looking closely to the water balance in existing urban areas.
5	Yes use raingardens, permeable pavements, biofilters bed (for cleaning and improvement), no so much retentions, use also the craig (gauis???). Water quality wise, based on some research I have seen (there is not a lot around there), they probably give at best 50% reduction in contaminant loadings. • The crais/gauis has a lot of issues as they need to be installed properly otherway they silt up, tree roots and everything get into them very quickly (hole craig plastic craif with geotech fabric wrap around them) and the tree roots found the water very quickly and tend to block them up. • Managing the silt getting into all of them is also very problematic. Biofilters bed can get significantly swamped with the silt, which then reduces the effectiveness in terms of cleaning and improving water quality. • Permeable pavements tend also to clog, there are good for a year or two but then they tend to clog and lose their permeability. • The other issue you have when you trying to put these things in near surface groundwater (like a retention basin or a craig-type systems) is that a soon as you get contact with the groundwater you are losing the effectiveness of your recharge because you are only recharging from the side of the basin or the craig, and not vertically. That has an impact on efficiency. **Evidences:** Some of these are our experiences in Adelaide and WA as well. Same that they are trying in far North Queensland with the underground dams as they say: "let pump the groundwater down and then we have some space to fill it up when it rains" but as the flood comes and fills them up, then they do not have more room to put the water. "As soon as you get this connectivity between surface water and groundwater, that is the end of the recharge". I think they are overestimating the volume of water that they are getting in.
6	Generally there are the national guidelines to follow with minor adaptations for local conditions (local guidelines). FAWB and the ones that Peter Dillon wrote for stormwater in 2009. Yes, they consider groundwater interactions. The

	stormwater harvesting guidelines that Peter wrote (that is the national guidelines) they do consider all the risks associated with pathogen and micro-biota, and potential pollution pathways.
7	WSUD installation in shallow groundwater: Basically, we do not install them in areas with shallow groundwater (less than 6 m below ground). If you start to install anything into those areas, then you will end up with all sorts of problems including: • Impact on near building and infrastructure. • Rise in water table, mounding and potentially flooding of cellars. • Ultimately, the shallow systems too because they are on a gradient and they will end up expressing somewhere down gradient, so you are in significant risk of waterlogging downgradient. So we are trying to be away of any real shallow systems. NO. We do not install any in high GW. We looked at them and decided that is not economical convenient. Because you got all the trouble to put the water, in the only way that you can mitigate any surface expression is by putting additional drainage so that seems counter intuitive.
8	No. Most of the time we follow the guidelines or local conditions and we introduce micro plunger holes. That is basically modify the design, put into large diameter aggregates and rock into the bottom of the large diameter holes and then gradually filling the hole with material of finer sequences. This is probably the only modification we made. Lined or unlined? It depends on what you are trying to achieve. We use both. If we are looking at stronger engineering systems basically then they are lined and the water is collected at the end, and then possible pump over the end to dry wells. The water is then allowed to infiltrate into the dry wells once that we removed all the sediments, and the other materials and nutrients, etc. (water quality achievements). The other one is just a simple treatment system by infiltration basin they are obviously unlined. **Evidences** The SA Water site at the Adelaide Airport is recharging the deeper aquifer (capturing the water) and it looks as combination of mechanical filtration and biofiltration material. They compare which ones are providing better water quality improvements. So that is a good comparison of different water quality treatment methods. We did the initial installation work but it is an ongoing work through SA Water. \
9	Impediments are multiples (method, data, and others). When you look at MAR even in a shallow aquifer **is the lagging**, they do not know. If it is a regulated groundwater system, regulators have not caught up with the issue around taking the water back out, banking the water, keep recharging for a period of time before you actually extract; also how far away from the point of recharge you can actually physically take the water out. There is a lot and lot of policy issues that needs to be resolved on how you better manage these and how to utilize the water that you have captured and saved. Most of the time we do the work for LGs. Local governments are

	onside with this but actually the regulators, the water resources managers and the EPA are impediments. And of course you need to consider public health as well. Most of the LGs are actively pursuing WSUDs we can actually bring them in but: • One of the issues is that councils often do not have the maintenance budget to maintain and manage them once the development is finished and the WSUDs are passed over to local councils. They suddenly face an increase in the maintenance budget depending on what form of WSUD has been put in. Quite often they do not have the budget for that and they do not see the value of the cost of maintaining it. When you are talking about green walls and small raingardens, councils rapidly rip them out when they see they will cost a lot of money. The problems with regulators are: • "They tend to change hats quite often", so you get through the issues dealing with nutrients and get the guidelines and the rules around what trigger value should be set for the various nutrients; then suddenly there is another one come up: is it the micro-pollutants, or is it the micro-biology, and so on and so on. • " The regulators are struggling with keeping up with the actual science and research that is out, so you have to go back and re-educate them every single time.
Flood Risk	
10-13	N/A
Groundwater Level	
14	Generally what will happen, depending on the density of housings and assuming that no one is using the groundwater, groundwater levels probably will decline as you get more impervious surfaces and more runoff, so your groundwater level goes down. With today's density of housing (70-80 % impervious area of the block) you significantly increase your impervious area and significantly reduce the amount of infiltration, then you groundwater level tends to decline. No. For new developments we do not need to quantify this. • Typically we look at what is going to be the water levels in winter and in summer and if it is going to express at the surface. • Also if they put the stormwater and sewer infrastructure: do they need to do any dewatering? And that is to get the infrastructure in place. No, there is not modelling required (developers will not pay for that). There will be a model component if dewatering is required. But that is the only thing they will do: a little bit of geotech work and the depth to water table to see if they can stay above it when they put the pipes underground. **Evidences** Mostly based on literature. A study I did (20 years old) showed groundwater

	level rising but that was in a ¼ acre section. “Under new urban areas or developments is something that has not been quantified too much”. Historically the regulators will have monitoring wells but not overall concerned with the shallow water table in urban environments. More typically looking at large irrigation demands (also water supply demands). There are a number of knowledge gaps on what happen to shallow groundwater systems moving it from a green field to an urbanised site.
15	We are currently doing one of those projects and we are undertaking preliminary modelling to see what sort of drainage we are going to need, no decision has been made yet on whether it is going to be an open drain or historical French drains (subsoils pipes). These seem to be the preferences but I suspect that will end up been open drain because is going to be cheaper for the developer. **Evidences:** The site is in WA, with high groundwater and inundated during the winter (waterlogged) in the Coastal Plain Area south of Perth. The project is for 18 month with some trials on infrastructure by mid 2018.
16	N/A
17	First call is soil maps if available and if not available then will do the site investigation. Site investigation is a combination of soil pits and bore logs (either existing or new going out the site and doing auger holes to get proper soil samples). Geotech report can be used when they are available but some of them are ok and others lack of the information we want.
18	Source of infiltration: really is probably pervious area allowed to infiltrate plus leakage from pipes and leakage for manhole covers. • There are numbers in the literature that suggest that even a new pipe network you will get 5-10% leakage from main water systems into a new development. • One path difficult to quantify that you can always put as a little factor as also some people may connect their down pipes to the sewer systems (that is not suppose to do but they do anyway) and that cause sewer overloading particularly during heavy storm events so you get additional flows coming out from manhole covers.
19	If there is no existing data: • We go out and do the site investigation that is install proper piezometers and go from there. In relation to using models, if I put my head as a regulator and somebody presents me model results without data and no field validation: • I will throw it out and say “it is rubbish because is all supposition and estimate”. “Models are as good as the data that you have to go in them.” If you have no data your model is not good.

	• You can do all sort of theoretical things but when you start looking at their variabilities you can put into the models you know: we estimate the vertical transmissivity and it was between .2 and 200 (four orders of magnitude) so the question is what is right?
20	For recharge rates you can use Penman Eq. to get a rough evapotranspiration and get an idea on what happens there in relation to recharge and the groundwater fluctuation levels. I have used lysimeters in the past in a shallow groundwater system however they have not been installed correctly (too much soil disturbance) but properly installed lysimeters will be a best way to get a proper estimate of recharge. You try to quantify recharge for models and you use bounds for it (based on water table fluctuations of such sort of that nature) before your put into your model. And of course the easy way to balance your model is by upping evapotranspiration. I will put some bounds on recharge values by having proper field data.
21	If it is absolutely critical, then it will come down to the approach that you are going to be using. Lysimeters that have been installed for a very long time are really very good but again they only reflect a particular soil type. However: • If you look at recharge over a large area with significant soil variability so you recharge rates vary for each soil type. • So it is getting out there and doing a proper soil mapping and field investigations. Question on quantifying recharge rates for different urban typologies using multi-techniques approaches: • “That would be the optimum approach basically and better than estimating it from a model”. • Models have their place but they have been put in too much focus and too much dependence in place in the results. I have already seem a number of litigation cases where models have been adopted and put in place and as soon they got into court they have been thrown out. It has become a really risky practice.
Groundwater Levels risk	
22	Providing that your open trenches and/or pipes are maintained, then it should work. The mathematics and the science was develop back in the 50s and it shows that subsurface drain and drain kept the groundwater level low.
23	Yes, generally because part of the flooding is groundwater expressing at the surface. This is in a different area of my experience but some people design for the 20 yr-ARI event and then they accept the risk that the 50 yr-ARI event down here is suitable. Groundwater comes into consideration by less clearance for infiltration.

<table>
<tr><td></td><td>No really. I have not seen any. No comments (in relation to disagreement with methods).</td></tr>
<tr><td colspan="2" align="center">Groundwater Levels Benefits</td></tr>
<tr><td>24</td><td>Vegetation, wildlife and greening. They have probably been there to maintain groundwater levels and ecological diversity and certainly wetlands.
Cooling effect by vegetation that has access to shallow groundwater or surface water areas where you are draining the water to and allowing it to evaporate (not the best use of the water) but if you have green corridors with trees with access to watertable, then evapotranspiration does have a cooling effect.
Tree belts to pump water (question by Carlos), Yes, but if high salinity water does not allow plants to grow, unless selection of species that don't mind get wet feet periodically in summer or winter; certainly vegetation is a good method to manage groundwater levels.
In Adelaide most councils encourage planting trees in new houses and streets. The only problem is the density of tree and whether one every 150 m can have a significant effect as green corridor; it does provide shade and evapotranspiration but unlikely a corridor for migration of creatures. This is still debatable. Your corridors might need to be wider and have more tree density to be really effective</td></tr>
<tr><td colspan="2" align="center">Groundwater Quality</td></tr>
<tr><td>25</td><td>Treatment on near surface groundwater or water that will be recharged. Yes, mostly for aquifer recharge.
We use passive treatments which are biofiltration beds and wetlands and mechanical treatment as well, and a combination of mechanical and wetland treatment as well. Mechanical methods as filters to remove sediments and UV treatment to manage bugs and so for. We try to flocculate out iron and other things and we keep the water agitated to prevent blue-green algae to growth, etc.
Evidences:
We have done it but it comes down to the questions when is it surface water or groundwater. A lot of the wetlands that we have installed here (SA) require top them up with groundwater during summer months to maintain functionality. But then the water is reinjected with surface water during the winter months.</td></tr>
<tr><td>26</td><td>Yes, we assess groundwater quality for 100-120 parameters; we look at the matrix of the aquifer itself through mineralogy work and then full screening of all the stormwater water quality for both runoff and natural streams. All done by comparison of data from monitoring programs. This is done for pre-development conditions (native water quality) and for post development; we use the information that is available to us from monitoring networks and they proposing that as a typical water quality runoff that you might get running from an urban area of a given sort.</td></tr>
<tr><td>27</td><td>N/A</td></tr>
</table>

Surface Water Flows	
28	N/A
29	N/A
30	N/A
Surface Water Quality	
31	N/A
32	N/A
Harvesting and Managed Aquifer recharges	
33	Yes, that is one of the project that we are currently working on managing high groundwater levels by draining those and taking that water to treatment and then using to recharge to a deeper aquifer. This is a MAR project that includes approval to do it.
34	Basically it comes down to economics and what you are trying to protect. If you are protecting infrastructure or easing to get infrastructure to the ground in comparison to say a plain field building site up, then managing aquifer recharge can be more effective, cost-effective means as suppose to applying a meter of fill over the area that you are trying to build up. If you can install some open drains or French drains under ground and manage the water levels, in that way is significantly cheaper and if you also have a deeper aquifer that you can recharge to. Question on water availability to recharge: there is always going to be some baseflow or low flow in summer especially if you use a drain so there is going to be always some summer flows, obviously not as higher as the winter flows. The drains will provide a minimum supply of water through the year and then you will pickup the storm event flows too. Pay to recovery the water: It depends and it can be instituted by local councils or by the developer himself. And if there is sufficient demand for the water by irrigators close by, then they can pipe the water to irrigators and help them to support their activities. This is where the economics comes into. If the groundwater supply is free and unlimited then you have not much demand (no much economic opportunity to offset your operating cost of pumping the water back).
35	Yes it is. In particularly in Perth, even the deeper aquifer system starts to show sign of stress and the regulators are considering reviewing the allocation volumes, so if there is an opportunity to maintain and manage POS by reducing shallow groundwater levels and reducing the impact on infrastructure by capturing that water, put it into the aquifer, and pull it back up again to maintain irrigation levels, at least you have a system that is pretty near in balance.
Development	

36	One alternative will be running piles on it, put piles deep enough to do the building. They do a little bit of that in Victoria, building in sand but without putting fill on it. The construction was similar to cofferdams, they put sheet piling down in the sand to a 28 m depth. It can be applied to houses and large buildings. I suspect it is going to be a very costly for a house.
37	Only one that I did work in a number of years ago in Mildura (VIC). It was advised by a consultant to put in 40 to 50 spear points around the development to lower the groundwater levels. Basically, almost every house will have 2-3 spears points in their backyard pumping water away constantly. We said that was ridiculous: a) for the cost, and b) how is it going to be maintained and the issue with water disposal. Then we basically ended up putting a drain in the middle of the street and that worked fine with significantly lower cost. Reports in Mildura Council (2006-2007).
General	
38	Key impediments: • Mostly the time it takes to the approval process. • The uncertainties with the regulators around on whether or not the options that you are proposing will be approved. • There is often quite a lot of work, negotiation to be done with the regulators before you can get things done that potential turn off potential developers.
39	Contested areas: trying to coordinate where the development areas are, when to occur and the timing and get there down early and get the baseline measurements before the development physically starts. No contested areas in terms of knowledge that I come across yet.
40	Peter Dillon (Flinders SA) and Don McFarlane (he may disagree with me).

Interview response sixteen (Craig Wansbrough)

Name Craig Wansbrough

Organisation

Interviewer

Question	*Response*
General	
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Water Balance	

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Water Quality	
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Flood Risk	
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Groundwater Level	
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Groundwater Levels risk	
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Groundwater Levels Benefits	
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Groundwater Quality	

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Surface Water Flows	
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Surface Water Quality	
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Harvesting and Managed Aquifer recharges	
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Development	
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General	
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Interview response seventeen (Carolyn Oldham)

Name	Carolyn Oldham
Organisation	
Interviewer	

Question	*Response*
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Water Quality	
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Flood Risk	
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