1 Landscape Water

Clearing of native vegetation and associated changes in land use have greatly altered the water cycle within the Avon River basin, resulting in reduced evapotranspiration, increased infiltration, and changes to runoff patterns. Increased infiltration and changes in runoff patterns have resulted in landscape-scale degradation including decline in water quality, erosion and salinity. More recently, changes in atmospheric conditions have begun to influence rainfall trends, which will further influence infiltration and runoff within the region and are predicted to intensify over the coming decades (IOCI 2012).

Changes to infiltration and runoff will have further downstream consequences, impacting environmental flows, mobilising nutrients and potentially exacerbating discharge of saline and acidic groundwater. Changes to land management practice, including increased capture and storage of runoff or construction of groundwater drainage, result in dramatic downstream impacts, particularly with insufficient planning and design.

Effective water management must consider landscape-scale processes and in particular the downstream impact of changes to land use and management practices that impact on the water cycle.

1.1 Rainfall Trends

Average annual rainfall in the region ranges from 297–445 mm. Our climate is dominated by hot dry summers due to the subtropical belt of high-pressure systems that progress across the region. During winter this belt of high-pressure systems moves to the north, allowing moist, unstable winds and associated low-pressure systems to dominate local weather patterns (IOCI 2012). As a result, approximately 80% of the region’s rainfall occurs during April–October.

Table 1. Average Annual rainfall and pan evaporation for Selected Centres in the Avon River Basin

Centre	Average Annual Rainfall (mm)	Annual Pan Evaporation (mm)
Northam	425	2204
Bencubbin	308	2810
Dalwallinu	297	2505
Southern Cross	317	2804
Lake Grace	336	2097
Pingelly	445	2004

Recent changes to regional rainfall have occurred throughout the region characterised by a reduction in rainfall over the period May–June, which has intensified and expanded in geographical area over the last decade. Prior to this change, early season rainfall was dominated by deep low-pressure cells, however since 2000 early-season rainfall has been driven by an increase in high-pressure systems (IOCI 2012).

The Avon River basin is generally experiencing an increase in high-pressure systems resulting in a 15% reduction in early-season rainfall, which is impacting crop establishment throughout the region. These changes in rainfall are consistent with early changes in the global atmospheric conditions, notably a 17% reduction in the subtropical Jetstream velocity and significant warming in the Southern Ocean (IOCI 2013). This has resulted in increased atmospheric stability over the region, translating into a downward trend in rainfall.

Climate models have been very effective in simulating current trends in rainfall in Southwest WA, and predict further rainfall reductions throughout the region in all months from May to October. High-pressure systems are predicted to become more prevalent, with their incidence expected to increase by 70% by the end of the century. The incidence of low-pressure systems is expected to decline by almost as much. Drying trends are predicted to intensify into the latter part of the 21st century (IOCI 2012).

1.2 Water Resources

The Water Corporation of Western Australia supplies drinking quality water to areas of the Avon River basin through the Integrated Water Supply Scheme (IWSS), known as “the Scheme”.

Of the estimated 27 GL/year delivered through the Mundaring to Kalgoorlie pipeline, approximately 11 GL/year is consumed within the Avon River basin. Approximately 61% of Scheme water delivered to the Avon River basin is consumed within towns, and the remaining 38% is used on-farm. Standpipes and community water supplies, transport infrastructure and the mining industry account for the remaining 1% (ACC 2008).

Dams are commonplace throughout the Avon River basin, primarily used for watering livestock and domestic garden use. For the most part, correctly designed dams and their catchments can be used as a satisfactory direct replacement for the IWSS if the intended use is agricultural or ex-house domestic. In general, dams provide an alternative to the reticulated supply network. However, the capital costs associated with developing alternative water supplies are a significant barrier to adoption (ACC 2008). Surveys undertaken within the Avon River basin have suggested that many dams in the region are substandard and/or poorly maintained and will be unable to cope with potential changes in rainfall patterns (ACC 2008).

Many landholders rely solely upon the Scheme for high-quality requirements (domestic consumption and spray use), but more recently the high pH of Scheme water has restricted its use in crop spraying (Martin Revel pers. comm. 2012).

The zone of ancient drainage, including the Central, Eastern and Southern sub-regions, has been internally drained for tens of millions of years. Whilst that area contains significant palaeochannels (up to 70 m in thickness), these generally have very large salt stores, and fresh groundwater is typically only associated with surficial aquifers, granite rock fractures and hillside seeps. Significant low-salinity groundwater resources within the region are restricted to remnant palaeochannels located within the narrow strip between the Meckering Line and the Darling Scarp.

Relatively few groundwater resources are used to supplement town water supplies, as the proximity of reliable water supplies to towns within the Avon River basin is limited by the underlying hydrogeology of the region. However, the towns of Quairading, Bolgart and Brookton both utilise groundwater resources to supplement town water supplies.

1.2.1 Resource Impacts

A formal assessment of the current state of water resources and the potential impacts of climate change on the security of water supplies within the Avon River basin is yet to be undertaken.

There is a long history of recurrent water supply shortages throughout the Avon River basin, and the impacts of climate change are likely to result in an increase in frequency and severity of water shortages (DoW 2011). Local reports suggest that water resources within the region are already stretched.

Preliminary assessments indicate that a 10% reduction in rainfall will reduce rainfall by 30%, resulting in very significant impacts to the security of water resources. Average dam reliability is predicted to fall from 93% to 70% as a result of a predicted 10% reduction in rainfall, based on a study of average dam storage and catchment areas undertaken for a series of sub-catchments within the Avon Arc subregion (ACC 2008).

It is generally accepted that maturing of agricultural soils and broad-scale adoption of no till has resulted in widespread reduced runoff in the last two decades. In addition, the increase in cropping in many enterprises in the Central, Southern and Eastern sub-regions has meant that water management infrastructure has not been well maintained in some instances. The more recent adoption of controlled traffic has also resulted in the removal of previously constructed contour banks. Predicted increased intensity of summer storms in changing climatic conditions may result in increased risk of episodic water erosion of soils. Removal of contour banks and reduced farming on the contour due to the introduction of auto-steer technology may further exacerbate the risk of water erosion.

Although based on limited information, the likelihood is that water resources within the region will become much less reliable over the coming decades, and this will limit future resilience of the Avon River basin's agricultural industry and community.

1.2.2 Resilience Assessment

A resilience attribute assessment can provide insight into the overall resilience of water resources (both environmental and human) and also shed light on appropriate management responses. (Longstaff et al. 2010).

Longstaff et al. 2010 identify the key attributes of resilience as:

- ***Resource Robustness*** *performance, diversity and redundancy*
- ***Adaptive Capacity****: institutional memory, adaptive response, connectedness.)*

The key attributes of resilience of regional water resources within the Avon River basin are discussed below.

1.2.2.1 Performance

The adequately or performance of water resources in the Avon River basin has not been clearly documented, but evidence suggests that many dams were constructed a long time ago, were silted, had insufficient catchment area or were becoming saline. This suggests that much of the agricultural water resource infrastructure within the region is poorly designed and not adequately maintained (Prout & Dodd 2004, ACC 2007). Certainly, much of the current water resource infrastructure was not constructed to maintain reliability in impending conditions predicted for climate changes (IOCI 2013).

1.2.2.2 Diversity

There is a low diversity of human use and potable water resources within the region, with water derived either from the Scheme or from surface water captured in dams. The region has very few fresh moderate to large groundwater supplies, although hillside seeps are common they are typically underutilised, but are a minor source of water.

1.2.2.3 Redundancy

There is very little redundancy built into the water resource infrastructure. Landholders connected to the scheme are generally totally reliant on the Scheme for water, usually with no effective back-up water supplies. Most landholders who are connected to the Scheme would literally run out of water within days of an interruption to supply.

Landholders who rely on surface water runoff and dams for water supplies often rely on standpipes for emergency supplies in the event that dam reliability fails.

Demand for high-quality spray water has increased in recent years due to an increasing reliance on chemical control or weeds and in-crop application of nitrogen. Standpipe water may be too alkaline for use as spray water in some instances, leaving some landholders with limited options for accessing crop-spraying water supplies.

1.2.2.4 Institutional Memory

During the period 1970 – 2000 state Government agencies provided water management services throughout the region, however over the last decade there has been a marked reduction in services. In fact, there is virtually no Government water management services remaining in the region, and there has been no development of private services to fill the gap. As a result there are very few individuals with effective water management planning skills remaining in the region.

1.2.2.5 Adaptive Response

The capacity of the industry and community to respond to the predicted tightening of water resources within the region is unclear, but current population trends and increasing farm debt suggest there is little capacity within the region to invest in the development, maintenance and upgrading of private and strategic water resources.

1.2.2.6 Connectedness

The region has little ability to share water resources due to the cost of transporting water. In addition, ageing water supply infrastructure is likely to require additional investment to ensure that the current water supply can be maintained (ACC 2008).

1.2.3 Conclusion

The Avon River basin would benefit from development and implement sub-regional water management strategies, including identification of priorities for water resource and environmental water management. Strategies should include urban, peri-urban, commercial, industrial and agricultural water demand and capacity, sub-regional professional capacity, integration of stormwater management works, sewage infill demand, and environmental water management issues.

The limited strategic planning currently being undertaken within the Avon River basin is likely to hamper effective response to a range of immerging stressors, in particular climate change, which is predicted to have a very significant impact on the security of supply of water resources.

Local government capacity to effectively manage urban stormwater is hampered by a limited understanding of stormwater infrastructure, poor asset planning capacity and limited understanding of changing catchment flow dynamics and associated impacts of infrastructure and the environment alike.

1.3 Salinity

Soil salinity is caused by evaporation of stored salts at the soil surface as a result of saturation of the soil profile. Saturation of the soil profile results either from rising groundwater or surface water inundation, or an interaction of the two. Recharge of groundwater occurs when rainfall exceeds evapotranspiration, which is greatest during large rainfall events and where water accumulates in the lower landscape, and during particularly wet periods. Salinity therefore tends to occur most as a result of discrete or episodic events, as opposed to a gradual process.

1.3.1 Resource Condition

The spatial extent of salinity in Southwest WA has previously been estimated by Landmonitor and by Australian Bureau of Statistics (ABS) surveys. Landmonitor analysis of salinity was undertaken for two snapshot periods in 1992 and 1998. ABS salinity surveys were undertaken approximately in five year intervals from 1955–2003. Due to the discontinuation of both Landmonitor and the ABS analysis, there is now no means for monitoring the spatial extent of salinity in Southwest WA. Groundwater monitoring via observation wells is currently the only means of estimating the spread of salinity with the region; however, groundwater monitoring provides an indication of groundwater trends rather than the actual spatial extent of salinity. In addition, large gaps in the groundwater monitoring networks limit its effectiveness as a stand-alone monitoring strategy.

In 1998, Landmonitor estimated that approximately 992,000 ha, 821,000 ha of which was agricultural land, Southwest WA was affected by salinity. Approximately 40% of that area (323,200 ha) was within the Avon River basin. Landmonitor identified areas of consistently low groundcover, and when combined with landscape position and other filtering provided a reasonable assessment of the area of salinity, albeit calibrated toward the severe end of the range. In other words Landmonitor's method contains both commission and omission errors, and probably underestimated the total area of salinity as it did not report areas of mild salinity or those areas revegetated with saltland pastures.

George et al. (2008) reported that in 2003 the area of land affected by salinity in Southwest WA was approximately 932,695 ha, based primarily on the 2003 ABS survey.

Salinity is not evenly distributed throughout the Avon River basin. The extent of salinity is a function of regolith characteristics, rainfall and time since clearing. Landmonitor estimated that approximately 4% of the Avon River basin was impacted by secondary salinity in 1998 (refer Table 2).

Table 2. Area (Km^2) of Salinity Impacting the Region (Landmonitor)

Km^2	Area	Salinity 1992	Salinity 1998	Proportion of catchment	Developed after 1992
Avon Arc	13,784	527	558	4.05%	6%
Central	27,066	1,373	1,574	5.82%	13%
Eastern	17,268	109	185	1.07%	41%
Southern	24,784	781	915	3.69%	15%
Total	82,901	2,790	3,232	3.90%	

The 2002 ABS salinity survey (ABS 2002) found that 2297 farms (79%) in the Avon River basin reported salinity impacts, and that 5.8% (450,000 ha) of the land area within the region was impacted by salinity.

Based on the information available, approximately 5.8% (450,000 ha) of land within the Avon River basin is impacted by salinity, 3.9% (323,000 ha) of which is considered highly saline.

1.3.2 Trends

The rate of salinity encroachment is also not even throughout the region. The rate of spread of salinity is a function of the rainfall, regolith characteristics and time since clearing.

Analysis of groundwater trends undertaken by George et al. (2008) indicated that shallow groundwater bores were more likely to have a falling or stable salinity trend since 2000, with bores drilled in discharge areas most likely to display a falling trend. Deeper bores and those contained within the valley hazard (low lying) areas of catchments yet to reach hydrologic equilibrium (where salinity development ceases) continued to rise, despite significant reduction in annual rainfall. George et al (2008) suggested that catchment response to clearing (presumably driven by annual rainfall, time since clearing and regolith characteristics) are the key drivers for groundwater response to rainfall. Those catchments that have reached equilibrium display fluctuating trends reflective of rainfall trends, while groundwater will continue to rise in those catchments that are still filling , although the rate of rise may be less pronounced during lower rainfall periods.

1.3.3 Avon Arc

Previous analysis of Landmonitor data provides a good indication of salinity trends in the Avon Arc.

Salinity development in the Avon Arc is largely restricted to the upper landscape associated with the remnant lateritic profile. Much of the Avon Arc is characterised by deeply incised valleys where most of the lateric profile has been eroded away by rejuvenated drainage during the Pliocene, resulting in profiles of shallow younger soils containing a limited salt store.

Deeply incised catchments to the west of the Avon River typically display 1–2% salinity by area, with those to the east typically displaying 2–5% salinity (ACC 2008). Most of the salinity apparent within the sub-region appears to have occurred prior to the 1990s (ACC 2008). Previous analysis of salinity trends within the Avon River also indicate a stable trend in river salinity after the early 1990s, suggesting that salinity in the majority of the catchment area is likely to have stabilised, with 85% of Avon River stream flow generated within the Avon Arc subregion (ACC 2008).

Salinity development within the Avon Arc appears to have largely reached equilibrium due to the area's relatively high rainfall, long period since clearing and generally shallow regolith. However, local area (paddock-scale) salinity continues to develop within the sub-region.

1.3.4 Central Sub-region

Salinity impacts almost 6% of the region, with the sub-catchments in the north-west most affected. The valley floor areas of the Central sub-region were cleared after those of the Avon Arc. The Central subregion is subject to lower rainfall than the Avon Arc and contains regolith much deeper than those adjacent to the Avon River.

Salinity on primary valley floors is well advanced, typically accounting for 50–70% of their area. Salinity impacts approximately 4–10% of lateral sub-catchment in the northwest of the sub-region and 1–4% of sub-catchment over the remainder (ACC 2008, Landmonitor).

Landmonitor indicates that much of the salinity impacting the primary valleys occurred prior to the 1990s, but salinity associated with lateral sub-catchments is more recent, and has continued since the 1990s (ACC 2008).

1.3.5 Southern Sub-region

The trend in salinity development in the Southern sub-region is similar to that of the central region, with a high proportion of the primary valley floor areas impacted by salinity prior to the 1990s, and salinity actively spreading into lateral sub-catchments.

Salinity impacts 2–4% of lateral sub-catchments, with salinity in early cleared sub-catchments adjacent to Lake Grace and Newdegate more advanced than in the later cleared areas east of Hyden, Varley and Lake King.

1.3.6 Eastern Sub-region

The lower rainfall and more recently cleared sub-catchments of the Eastern sub-region have the least developed salinity within the Avon River basin. Primary valley floor areas were still becoming saline during the 1990s and 1–2% of lateral sub-catchments were impacted by salinity (ACC 2008).

1.3.7 Future Trends

There have been very few published assessments of the extent of salinity at hydrologic equilibrium. Most papers reference Short & McConnell (2001), and assume the entire valley hazard area defined in the Landmonitor project (defined by 2 m vertical height above drainage lines) will eventually be impacted by salinity. However, there is no scientific basis for using height above stream basement for determining salinity risk, nor is there any evidence that the entire valley hazard area will be impacted by salinity at equilibrium. In fact, salinity impacts only 20–40% of valley hazard areas within sub-catchments in the Avon Arc, where salinity has largely reached equilibrium. In the northwest of the Central sub-region, where hydrological processes are well advanced, salinity similarly impacts 30–40% of valley hazard areas (Landmonitor).

1.3.8 Impacts of Climate Change

No formal analysis of the impact of climate change on the development of salinity has been undertaken to date. However, trend analysis undertaken by DAFWA indicates that as sub-catchments reach equilibrium, shallow bores tend to rise and fall with rainfall patterns (George 2008). However, in sub-catchments where hydrologic equilibrium has not been reached then groundwater bores continue to rise, suggesting that future salinity development is likely, albeit less rapidly under reduced rainfall conditions.

Recent work undertaken by Coles et al. (2009) and Callow et al. (2010) suggests that salinity process are often driven by local-scale surface–groundwater interactions in response to major rainfall events. George (2008) also suggested that major groundwater responses in the last two decades have coincided with major episodic rainfall and associated runoff events, implying that surface water interactions are also a key driver of episodic recharge associated with extensive valley floor inundation.

Coles et al. (2009) and Callow et al. (2010) suggested that reducing inundation associated with regular (< 1:3 ARI peak flows) can significantly reduce the development of salinity through decreased surface–groundwater interaction. As a result construction of surface water management works to convey the 1:5 ARI peak flow may be sufficient to reduce salinity development within lateral catchments where flows are able to be effectively conveyed downstream, where it is safe and reasonable to do so.

Rainfall patterns over recent decades indicate that catchments are becoming less wet during winter as a result of reduced autumn and early winter rainfall. Climate change predictions for the region are for reduced rainfall for May through October as a result of less atmospheric instability creating more high-pressure systems and fewer low-pressure systems (IOCI 2012). Reduced rainfall is predicted to be partially offset by higher-intensity summer storms, potentially resulting in increased valley floor inundation driving surface–groundwater interactions.

The limited evidence available indicates that salinity will increase across much of the Avon River basin, particularly in the Eastern, Central and Southern sub-regions where sub-catchments have not yet reached hydrologic equilibrium. It is likely that episodic rainfall events and subsequent surface–groundwater interactions will be increasingly important in driving episodic salinity development.

Significant additional salinity development within the Avon Arc seems unlikely, and salt loads within the Avon appear relatively stable, but declining flow resulting from changing rainfall patterns presents the potential for greater concentrations of salts in river flow.

1.3.9 Revegetation

Previous investment into revegetation to control salinity has resulted in establishment of hundreds of thousands of trees in shelter belts alleys and block plantings. Often tree planting provides additional benefits, improving and enhancing biodiversity, reducing wind erosion and providing shelter for domestic stock in addition to improving aesthetic values.

Revegetation is most effective in controlling salinity in situations where local groundwater systems exist. In particular above hill side seeps and intercepting perched fresher groundwater. This is because for trees to be effective in controlling groundwater recharge they must actually be able to intercept groundwater prior to recharging deeper aquifers. Revegetation of discharge sites - where salinity is occurring in lower landscape positions – requires the use of extremely salt tolerant spp such as saltbush and/or blue bush. Revegetation of salinity areas with salt bush provides a range of important functions including:

- Returning land to productive use.
- Reduce erosion of saline soils through soil stabilisation
- Reduce salinity of runoff through reduce concentration of salts at the soil surface.

If used in association with effective surface water management, revegetation of saline areas with salt bush provides the most effective mechanism for management of saline landscapes and reducing downstream impacts associated with saline runoff.

The use of revegetation for effective salinity control is requires the right plants in the right landscape position and therefore requires effective investigation and integration with other flow control structure, in particular surface water management.

Revegetation has other very important benefits associated with improving and enhancing biodiversity, reducing wind erosion and providing shelter for domestic stock. Perennial vegetation also provide an important carbon store and may have other benefits associated with regional climate regulation (McAlpine et al 2007). However, the extent of revegetation required to achieve regional climatic benefits remains unclear. Presumably, significant changes in the area of vegetation land cover would be required to achieve changes in climatic conditions.

1.3.10 Drainage

Deep drains (or groundwater drains) have been employed by some landholders in an attempt manage the impacts of salinity on agricultural land. In 2002, the ABS (2002) reported that in Southwest WA landholders had constructed 98,000 km of earthworks for the purpose of managing salinity. No subsequent analysis is available, preventing an accurate assessment of the current amount of groundwater drainage in Southwest WA.

There are two key issues surrounding the use of drainage for salinity control in the region: the effectiveness or performance of drainage and the downstream impacts associated with groundwater discharge from drainage.

Given the amount of drainage constructed in Southwest WA, there has been surprisingly little research undertaken into the effectiveness of drainage in controlling salinity.

In many cases it appears that while deep drainage may generate groundwater flow, the effective influence of the drain is often not sufficient to allow land to be returned to effective agricultural production (Cox 2010).

The effectiveness of deep drainage is determined by the lateral extent of the drain's influence on the surrounding water table, which is dependent on the depth of the drain and soil characteristics. The Department of Water report that in more responsive soil types the draw down is up to 0.5m over a distance of 150 m for a 2.0 – 2.5 m drain (Dogramaci & Degens 2003). However, for drainage to be effective it must reduce water table to below the critical depth to prevent capillary rise of salt to the soil surface, which is typically 1.5 – 2m below natural surface.

Drainage for groundwater control in other parts of the world, and for irrigation control typically involves a series of drains constructed parallel to one another. The distance separating the drains being a function of the depth of drain and hydraulic conductivity of the soil, with the drainage network designed to maintain groundwater levels below the critical depth, of say 2m (Cox 2010). If drains are not constructed in parallel, as in the majority of cases in Southwest WA where a single drain is constructed in isolation, then the external influences of the surrounding catchment impact groundwater levels within the zone of influence of the drain. In many cases this appears to render the drain largely ineffective in achieving effective groundwater control (Cox 2010).

Drainage, where effectively implemented, is merely the precursor for managing saline soils. Firstly stored salts must be leached from the soil profile, which in low rainfall environments and heavy soils may be a slow process. Furthermore, when highly saline, acidic groundwater is drained from loamy and clayey soils changes to the soil chemistry often occurs, which must be rectified if land is to be successfully returned to production. High sodium concentrations in clay soils post-drainage typically lead to development of sodic soils. Sodium must be leached from soil profiles, often requiring addition of high rates of calcium in the form of gypsum in addition to sufficient organic matter to improve soil structure.

Groundwater in many parts of the wheatbelt is high saline (saltier than seawater) and very acidic, with pH often in the order of 3 – 4. In addition the groundwater also contains high concentrations of dissolved aluminium, iron and trace metals like lead, nickel, copper, zinc, cadmium and in some cases selenium and uranium (Shand & Degens 2008). The high concentrations of iron and aluminium in groundwater mean that the total acidity of much of the groundwater within the Avon River basin is very high, meaning that large qualities of neutralising agents like caustic soda of limesand are required to neutralise it (Shand & Degens 2008).

Approximately 50% of groundwater samples collected and tested throughout the wheatbelt are considered moderately – highly acidic (< 5.5 pH_{cacl}) (Lillicrap & George 2008). Saline, acid groundwater containing trace metals presents a very significant environmental hazard to the receiving environment (DoW Unpublished, Jones et al 2009, Shand & Degens 2008). Acid groundwater discharge from drains has the capacity to acidify receiving environments such as native vegetation, lakes and rivers, in addition to potentially leading to accumulation of heavy metals in surface environments, leading to toxic effects in aquatic organisms and bio-accumulation within aquatic food chains.

Not only does drainage effluent present a potential environmental hazard, it can also result in contamination of downstream agricultural land. As a result it is essential to ensure that disposal of groundwater from deep drainage is undertaken in an environmentally responsible manner. Safe disposal or effective treatment of groundwater requires appropriate level of investigation and design to ensure that materials are not reactivated during periods of high flow, or that systems do not fail and adversely impact downstream natural or agricultural environments.

A key driver impacting the successful implementation of groundwater drainage in the region is that the value of production from treated land is not sufficient to justify the extent of investment required to construct drainage properly, undertake effective post drainage rehabilitation of soils and responsibility treat or disposal of drainage effluent. (DoW unpublished).

All too often in the past, drainage has been constructed with poor planning and limited consideration for impacts on downstream environments. As a result much of deep drainage constructed within the region has been largely ineffective in protecting and/or rehabilitating saline land, and has resulted in some cases in severe downstream environmental impacts.

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