Predicting impacts of current and future salinity on hydrology of major river systems of the Avon Basin of Western Australia

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Introduction

Nearly twice the size of Tasmania, the Avon Basin is the largest surface water drainage basin in the south–west region of Western Australia and covers about 118,000 km^2 (about 11.8 Mha). Mean annual rainfall ranges from 750 mm in the west to 200 mm in the east. The basin is characterised by relatively flat low rainfall crop and pasture country in the east and middle regions and hilly high rainfall deep rooted vegetation in the west. Most of the central and eastern catchments are largely internally drained and has an extensive network of salt lakes. The groundwater resources of the region are generally unfit for domestic and agricultural use. The groundwater salinity ranges from 2,700 mg/L in the west to over 55,000 mg/L in other parts of the basin. Numerous rural towns and associated infrastructure and heritage and cultural sites lie within the Avon Basin. A network of around 25,000 km roads and 1,900 km railways exists in the basin.

The hydrological and hydrogeochemical impacts of clearing of native vegetation for agriculture in the Avon Basin, a major part of the wheatbelt of Western Australia, are profound and enduring (Hatton *et al.*, 2003). Changes in the underlying hydrological and hydrogeological processes on grand scale in space and time caused excessive accessions to groundwater resulting in the development of shallow water tables, increased waterlogging and flooding, and salinisation. The hydrological impacts of land clearing for agriculture have been studied and reviewed in detail by numerous studies (McFarlane *et al.*, 1993; Nulsen, 1993;and Schofield, 1990). The impacts were resulted from the replacement of native sclerophyll vegetation with annual crops and pastures over a major portion of the Avon Basin. Some of these impacts were highlighted relatively very early by Bleazby (1917), Teakle and Burvill (1938) and Wood (1924) but had no influence on land policy. Around 65% of the Avon River Basin was cleared for agriculture most of which occurred between 1940 and 1970. One of the major consequences of clearing was a dramatic increase, typically two orders of magnitude, in diffuse and localised groundwater recharge (George, 1992, Peck and Hurle, 1973; Salama *et al.*, 1993).

Excessive groundwater recharge resulted in the development of dryland salinity mostly in lower parts or flat valley floors of the basin. Already around 5% of the basin area is affected by dryland salinity. It is predicted that if current climatic trends continue into the future around 25 to 30% of the basin will be at the risk of salinisation with annual cost of its consequences in the order of hundreds of million of dollars. This study was aimed at predicting the impacts of current and future salinity on the major river systems of the Avon basin if nothing is done to treat or manage this dryland salinity. The objectives were to predict the impacts of impacts of current and future dryland salinity in the Avon basin on:

- groundwater levels and groundwater salinity;
- flows and loads of major river systems
- peak flows or flooding risks; and
- salinity of the major river systems.

Material and methods

The hydrological model called LASCAM (LArge Scale CAtchment Modelling) was used for this study. The LASCAM (Sivapalan *et al.*, 2002) model is a large scale conceptual hydrologic model. The LASCAM model was developed to predict the impact of climate and land use changes on fluxes of water, salt, sediment and nutrients in forested and agricultural catchments in Western Australia. It operates on a daily time step and relies on calibration of model parameters against one or more observed records of streamflow and load. LASCAM is applied separately to each of these sub–catchments and the resulting flows are routed along the stream network. A global set of model parameters is used. Routing is achieved through a simple but efficient scheme in which bulk stream velocity is dependent on streamflow volume.

LASCAM was calibrated using historical data (1970 to 2003) such as GIS data, rainfall, streamflow, stream salinity, leaf area index, soil properties, evaporation and regolith depth from the Avon Basin. The quality of the calibration was assessed by evaluating how well daily streamflows and salt loads at several locations within the basin were predicted. Calibration performance targets were set, with the expectation that the predictions at most sites would meet or exceed most of the targets.

The calibrated model achieved most of the performance targets. Monthly and annual streamflows were predicted more accurately than daily streamflows. Salt loads tend to be under estimated in this model. The salt load predictions were compromised to some extent by the limited amounts of observed data for some gauging sites. In general, the model predictions for lake discharge and storage appear to be quite satisfactory given the extreme difficulty in establishing reliable and robust accumulation and discharge characteristics for the modelled lakes. Overall, good calibration was achieved for the model as most of the performance targets were met. Given the paucity and reliability of the historical data available for calibration, it was significantly better than previously calibrated models.

The calibrated model was used to generate hydrological predictions of the impacts of current and future salinity if nothing is done to treat dryland salinity. The LASCAM model runs were from 1965 to 2100. After 2003, the 28-year period of observed weather data from 1976 to 2003 was repeated about three and a half times to extend it to 2100. Land use, vegetation cover and lake characteristics were assumed to remain at their 2003 levels. The outputs included predicted groundwater levels, streamflows, salt loads and lake overflow frequencies and salinities for all 108 subcatchments of the Avon basin. Results are reported for only eight key sites: Avon River at Great Northern Highway, Mortlock North River, Mortlock East River, Avon River at Northam, Salt River at Qualandary Crossing (Yenyening), Lockhart River, Wakeman Creek at Narembeen and Yilgarn River.

Results and discussion

The model predicts that the groundwater levels will continue to rise in most of the wheatbelt. The rate of rise will, however, become slower over time. Most subcatchments of the Avon basin will reach at (western catchments) or near (eastern catchments) equilibrium conditions by 2100. Further appreciable rises in the groundwater levels would not be expected after 2100.

As a consequence of these rising groundwater levels, the annual streamflows will increase over time (Table 1). The rate of their increase varies across the basin and is greatest for the eastern subcatchments. At the basin outlet the mean annual streamflow increases by about 10% from 298 to 328 GL/year during the first quarter of the twenty-first century. The streamflow at Yenyening increases by about 45% from 18 to 26 GL/year. Currently, most of the streamflow is generated in the wetter subcatchments in the far west. Due to the development of additional areas of shallow watertables, the streamflow generation from most catchments increases over time. By 2004 to 2031, small increases in streamflow generation are predicted in most catchments. The increased moisture in the surface layers also increases surface saturation and leads to increased saturation-excess runoff, but the trend in annual peak flow rates is not significant. This indicates that the increases in annual total streamflows are caused primarily by increases in baseflow, rather than in surface runoff.

Increased stream salinities and salt loads are predicted over time. The development of shallow watertables increases the discharge of usually hypersaline deeper groundwater into shallower aquifers and surface water systems resulting in higher stream salinities and salt loads (Table 1). The largest increases in salinity are in the eastern wheatbelt. The salt loads increase faster than streamflows throughout the basin. The mean annual salt load at the basin outlet almost doubles by the end of first quarter of the twenty-first century (Table 1). For the same period the mean annual salt loads from Mortlock North and East also double. At Yenyening, the salt load increases to about 2.5 times the current load. The largest increase in the salt load is from Lockhart where it increases by almost 4 times the current load. The flow weighted salinity of all major river systems will increase over time. At most gauging sites reported in the Table (1) increases in flow-weighted salinity of more than fourfold the current levels are expected by 2100. By 2100, the largest increase in the flow-weighted salinity is expected at Lockhart where it is predicted to increase 9 times the current levels (Table 1).

The predicted salt yields (from where the salt is sourced) are largest for the western catchments during the first quarter of the twenty-first century because the bulk of streamflow at the basin outlet is sourced from these catchments. The salt yield from eastern catchments is minimal for the same period mainly due to huge storage capacity of these catchments, having large salt lake systems and relatively flat and wide natural creeks and streams. The region to the west of Wongan Hills, Dowerin, Wyalkatchem, Kellerberrin and Corrigin remains an active salt exporter during the first quarter of the twenty-first century. Presently the largest salt yields (more than 60 t/km^2 year) are from parts of the Brockman River and some of the subcatchments near Northam. Areas producing more than 40 t/km^2 year include the subcatchments along the Avon River between Toodyay and Yealering, and in the lower Mortlock East. Increased streamflows will result in increased overflow frequencies and volume of lake discharges over time. Discharge frequencies increase for most of the non-terminal lakes. Several of the lakes that are near-terminal in the twentieth century fill quite frequently by the late twenty-first century (e.g. Kurrenkutten, Jilakin). There are also significant increases in (flowweighted) the salinity of lake discharges, which reflect the increased salinity of lake inflows.

Table 1 Mean annual streamflow, salt load and flow-weighted salinity for eight key sites

Key sites	Water (GL/year)			Salt (kt/year)			Flow-weighted salinity (g/L)		
	1976–2003	2004–2031	2073–2100	1976–2003	2004–2031	2073–2100	1976–2003	2004–2031	2073–2100
Great Northern Hwy	298	328	399	1366	2619	7400	4.6	8.0	18.5
Mortlock North	18	22	33	128	290	926	7.1	13.2	28.1
Mortlock East	22	27	37	178	345	804	8.1	12.8	21.7
Northam	128	147	193	770	1603	5100	6.0	10.9	26.4
Yenyening	18	26	57	237	599	3336	13.2	23.0	58.5
Lockhart	6	10	30	49	194	2208	8.2	19.4	73.6
Narembeen	1	2	6	7	23	218	7.0	11.5	36.3
Yilgarn	8	9	17	50	102	520	6.3	11.3	30.6

Conclusions

The model predictions showed that most of the eastern catchments will reach near equilibrium conditions by 2100 and western catchments will reach equilibrium before the turn of the century. The groundwater levels and salinity will continue to rise and stream flows will continue to increase over time. More salts will outflow from the basin over time with increases in the salt affected area. Similarly the overflow frequency of salt lake systems will increase over time because of increased flows from larger saturated areas and subsequent increases in baseflow and saturation excess runoff. These increases have been occurring in some parts of the Basin since European settlement and are in response to the widespread replacement of native vegetation with shallow-rooted crops and pasture. Viney and Sivapalan (2001) conclude that streamflows in the Avon catchment increased five-fold between the onset of European settlement and the end of the twentieth century. The results presented in this study suggest that while these increases continue, the rates of increase are now slowing and that most parts of the catchment will (in the absence of further land management changes) reach equilibrium some time during the current century.

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